POWER SYSTEM COMMUNICATIONS:

POWER LINE CARRIER AND INSULATED STATIC WIRE SYSTEMS

REA BULLETIN 66-5

RURAL ELECTRIFICATION ADMINISTRATION • U.S. DEPARTMENT OF AGRICULTURE

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FOREWORD

REA Bulletin 66-5, "Power System Communications: Power Line Carrier and Insulated Static Wire Systems," is one of a series of REA bulletins dedicated to power systems communications. This publication is the first of its kind to specifically deal with rural electric cooperatives' design and implementation requirements for this particular communications transmission media and is an excellent reference guide for fundamental engineering considerations. The subject area covers systems engineering, design considerations, equipment and facilities, operating parameters, performance analyses, operations and maintenance.

The step-by-step presentation of the material in this bulletin should be of great benefit to all cooperative engineers and engineering firms and particularly helpful to relatively inexperienced engineers beginning their careers in power systems communications.

David G. Hamil

Administrator

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AND

INSULATED STATIC WIRE SYSTEMS

POWER SUPPLY AND ENGINEERING STANDARDS DIVISION
RURAL ELECTRIFICATION ADMINISTRATION
U.S. DEPARTMENT OF AGRICULTURE

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I. GENERAL

A. Introduction:

Power Line Carrier (PLC) and Insulated Static Wire (ISW) offer two of the most widely used and important communication means to the electric utility field. Efficient and reliable communications are vital to every electric utility system. Communications are required between and among points of operation, generation, transmission, distribution, and maintenance, and operation crews. Today's power systems communications include requirements for transmission of voice, telemetry, control, and system protection signals. Voice communications may be simplex, duplex, multi-channel, and/or voice plus data within the speech band. Likewise, telemetry and control signals may be used for remote alarm systems, analog and digital telemetry, automatic generation control (AGC) and supervisory control and data acquisition (SCADA). Transmissions of system protection information involve relaying, equipment protection status and information, and line protection signals.

The application of either PLC or ISW depends to a large degree on two factors: the type of information to be transmitted, and the structure of the power system involved. Further, the use of the phase conductors of the transmission line for PLC, versus the use of an insulated ground (static) wire for ISW, for the transmission of relay information may pose serious questions of both application and design for the transmission engineer.

B. Purpose:

The purpose of this bulletin is to provide a comprehensive manual for the application, evaluation, and design of PLC and ISW communications systems for use by both REA and Borrower engineering staffs. To provide a system that will do the job intended, which is also economical, requires a substantial amount of information, usually more than is available. The need for this information may not be readily apparent. However, the proper selection of equipment, and the consideration of all possibilities and limitations, can only be made after a careful analysis of the many factors relating to the functional requirements and the transmission parameters. It is anticipated that this bulletin will serve an analysis of this kind. It is not meant to supplant a formalized education, rather, to serve as a supplement thereto. The subject matter covered in this bulletin is extensive, and for this reason, formal proofs are not offered, nor could they be supported within the scope of this bulletin. The engineer is asked to

view this bulletin and its contents as a compendium of the current published thinking on the subjects of PLC and ISW within the restrictions noted herein.

C. Scope:

When dealing with the subject of communications, it is necessary to treat it as a whole at first, and then dissect it into its constituents. This bulletin is organized into six sections: General, System Engineering, Operations and Maintenance, Glossary of Terms, Standard Symbols, and Bibliography. The general section provides background information, introduces the roles of the various regulatory agencies, presents an overview on the application of PLC and ISW in present systems, and investigates the trends in both equipment and in system usage. Section II- Systems Engineering, treats the methodology and use of PLC and ISW, providing the details of their system characteristics, planning and analysis factors, design considerations, engineering procedures, equipment, and facilities description, the system operating parameters and their use in the performance analysis, and finally, a step-by-step procedure examining the calculations required for the signal-to-noise determination of voice, data, telemetering, and protective relaying circuits. The Operations and Maintenance of PLC and ISW systems is discussed in Section III, which covers overall system operation and function, management, manpower, support and maintenance requirements, plus design standards and system objectives, testing and evaluation. The Glossary of Terms covers all specialized terminology used in the bulletin and is commensurate with accepted industry definitions. The Standard Symbols contained in Section V are presented in single function form. It is anticipated that the reader will follow multiple function usage of symbols where such need dictates. The Bibliography contained in Section VI is representative of the subject matter presented herein, but is by no means all inclusive. It is hoped that the bibliography will serve to further the knowledge of the reader--especially in some of the more complex facets.

It is neither anticipated, nor within the scope of this bulletin, upon its reading, to mold a PLC design engineer. Rather, it should, and does provide, the requisite introduction into the field of PLC and ISW system engineering.

D. Background:

Virtually any phase conductor of a power line can be used for carrier transmission. Power Line Carrier has its origins with the development of the electron tube. Its inception dates back as early as 1902 when a patent was issued to F. Bedell for a

"method" for----utilizing the constant-potential mains of an alternating or direct current distribution system for the transmission of intelligence by any suitable means, such as a telephonic apparatus-----to one or more suitable receivers at a distant point. As early as 1920, power line carrier equipment was being installed on a regular basis. The problem of frequency assignments for the various signals transmitted has been, and still is, a major consideration, as well as a limitation, in the use of PLC.

E. Regulatory Constraints

Power Line Carrier (PLC), the means for carrying voice communications, relaying, control functions, and other media over high power transmission lines of power generation and distribution companies facilities, is, within itself a communications system, and as with other means of communications systems, is subject, at times, to Regulatory Requirements by agencies of the United States Government. Since we are dealing primarily with PLC herein, we will refer only to the agency responsible for the regulation of PLC. Within the United States, the utilization of the technique of PLC falls within the control of the Federal Communications Commission (FCC), an agency set up by Congress as a result of the Communications Act of 1934. The purpose of the FCC is to regulate non-government radio stations, and facilities using the airwaves for the transmission of communications media of all kinds; to promote national and international public communications, and to provide for orderly use of the radio frequency spectrum within the borders of the United States.

While most forms of radio communications require licensing by the FCC, the use of PLC is not subject to licensing procedures for its operation. There are, however, certain restraints placed on PLC by the FCC, namely in the use of the frequency spectrum and power radiation.

Power lines of any voltage may be used for communications purposes, however, regulation of use of the frequency spectrum is controlled.

Within the United States PLC frequencies are restricted to the area between 30 to 300kHz. While the lower limit is not an absolute lower limit in the use of the spectrum, the bandwidth at this lower frequency is not normally adequate, or practical for use.

The upper frequency limit is due to the extensive use between 300 and 415 kHz for aircraft and aircraft control and navigational facilities, and the use of the upper frequency

by PLC is more rigidly controlled and monitored by the FCC.

Control on radiation is placed in instances wherein excessive radiation could cause interference to licensed communication facilities or services, and in instances such as this it is strictly prohibited. Otherwise, transmitted power levels are not restricted.

F. Present Systems and Applications:

Modern day PLC and ISW communications systems evolved from tube-type technology and limited application--protective relaying into solid state technology, and multi-discipline application during the last ten years.

Today's PLC systems provide a communications reliability limited only by the power system transmission reliability and transmission line characteristics. PLC signals travel hundreds of miles without necessity of repeater terminals. The system design and performance are under the user's control. Special conditioning and regulations may be stipulated by the user and only in those circuits the user deems necessary. Equipment maintainability and logistics control may be performed where the logistics of repair dictate; the substation for example, or a distribution center. The proximity of the power system obviates the need for emergency or auxillary generators. In terms of economy, the transmission path is paid for in the expense of the power transmission costs. A PLC communications system may provide from 30-50 four kHz channels for the overall system. This is generally adequate for most power system communications needs.

Voice communications may be either one-way (simplex), or two-way (duplex). The voice communication channel may be designed or arranged to accommodate a combination of speech plus other narrow band signals and is used in relaying or teletype circuits. The PLC system is also capable of providing multi-channel voice communications through direct application of the carrier signal or through the use of multiplexing techniques--the combining of several audio frequency range signals onto a single carrier frequency.

Telemetering and control signals may be either analog or digital. The principle uses of these types of signals are in remote alarm systems, analog telemetering, automatic generation and control, and supervisory control and data acquisition.

The PLC system also provides for the transmission of system protection signals as used in pilot relaying for equipment and line protection.

The Insulated Static Wire (ISW) is also used for carrier channels and have been used successfully for both voice communications and transmission of control signals, There has been some indication of the use of ISW for protective relay functions, however this application of ISW has not met with any measure of success, or approval by protective relay engineers. Static wires used for transmission of carrier channels usually have insulation levels ranging from 7.5 to 15.0KV, and these levels, at times, create the possibility of insulation flash-over during a fault, which would greatly attenuate the signal and prevent proper relay operation.

PLC is capable of transmitting various modulation formats (signals). Among the types of signals that are transmitted over a typical PLC system are: amplitude modulation (AM), frequency modulation (FM), single sideband, (SSB), frequency-shift-keying (FSK), and keyed carrier.

In power systems where a closed loop in power lines exists, PLC affords redundancy of transmission in the event of either loss of power line continuity or for equipment that is difficult for other types of transmission media to provide on an economical basis. In a looped system, two directions of transmission exist from any station, clockwise, and counterclockwise. PLC equipment manufacturers have taken advantage of this configuration and now provide equipment which alters the direction of transmission within a loop upon the loss of continuity in the power system transmission line or in a communications failure -- thereby effectively providing a dual direction of transmission -- inherent in the power system.

The PLC channel is generally configured as a "3002" unconditioned channel. This denotation is essentially a common carrier term that applies to a specific common carrier tariff. PLC channels have demonstrated successful transmission of up to 1800 bits per second (bps) with error rates on the order of 1 in 10,000. On certain other transmission lines PLC has demonstrated a 2400 bps capability equal to that commonly obtained at 1800 bps.

Another factor often overlooked in the planning and selection ofcommunications for power systems is that as a result of the proximity of PLC to the user, the problem of both interfacing and lengthy wire runs is almost non-existent. This is particularly important for transmission of control signals from the sub-stations and plant facilities to a distant centralized control system where excessive cable or wire runs from transducer elements, relays, and other media, may necessitate the use of an intermediate line driver.

In summary, both PLC and ISW communications systems can provide excellent voice and data communications. They are capable of handling and modulating format required by power systems communications. Their proximity to the user and the use of the phase conductors for transmission of signals makes PLC and ISW one of the most viable and economical means of communications for the power system.

G. Trends:

The PLC systems currently in use span a 20-year technology. Tube equipment is being replaced by their transistorized and solid-state counterparts. Large Scale Integration (LSI) will both simplify and diminish component size. The use of compandors to improve voice channel performance will increase as the technology of compandorizing moves forward. While most present circuits on PLC and ISW systems are "unconditioned" (no special equalization) it is anticipated that the use of adaptive equalization and regulation will find its way into PLC and ISW systems. As this occurs, the transmission of data rates up to 4800 bps will become a reality. Centralized maintainance and testing of data lines is already taking place as the use of more sophisticated modems for data transmission occurs. The introduction and wide use of Supervisory Control and Data Acquisition (SCADA), Automatic Generation Control (AGC), remote switching, and Load Management communications will place new demands on both PLC and ISW communications systems. Telephone switching capabilities and remote PABX service will be comparable to that offered by the common carriers, but on a smaller scale. It is not anticipated that transmitters will increase beyond their present 100 watt application--the present voice quality will remain about the same. The use of PLC as a base station repeater to extend mobile radio service for maintainance and operations is a distinct possibility. Component reliabilities will be comparable to that offered by other communications media. There is an indication that PLC and ISW communications will lose some of their present frequency utilization to other services. Should this happen, it may attack the viability of this vital means of communications of the power industry.

II. SYSTEMS ENGINEERING

A. Power Systems Communications:

Power systems require both efficient and economical communications between and among facilities within the power system. Figure II-1 is a synopsis of some of the communications required for the efficient management and operation of a power system.

Supervisory Control is applied to circuit breakers, transformer tap changers, capacitor banks, DC station service, oil and winding temperatures in transformers, AC station service, transformer highside overcurrent lockout relays, supply lines, status for transformer switches, voltage information, and load-shedding relays.
Alarm systems are monitored for status and security against false operations. Status indication and alarms may be typically used for: automatic tap changers, bus voltage, circuit breakers, gas turbine unit alarms, line synchronization, and others.

Automatic Generation and Control (AGC) involves the unit commitment and energy management of the generation system. AGC determines the appropriate generation control action to satisfy power system requirements, and monitors the performance of this control. Within the control function, the power required from each generator is calculated and control pulses are sent in response to these requirements. Possible system errors such as inadvertent interchange, time deviation, and frequency are monitored and corrected. Programs are available which calculate generation requirement to satisfy estimated future system loads.

Telemetry systems for power applications provide such data as bus voltage, feeder current, watts, vars, kilowatt hours, kilovar hours, and alarm functions.

Relaying--protective, pilot, and supervisory--are still used in the day-to-day operations of power systems as is voice communications for the day-to-day operation and maintenance of the power system.

Economic Load Dispatch communications involve the use of security analysis, resource, load, and support functions data for the proper execution of commitment and resources within the power system.

Increased use is being made of facsimile transmission for record log data, as is television for plant security and surveillance.

POWER SYSTEM COMMUNICATIONS PROVIDE FOR TRANSMISSION OF

- SUPERVISORY CONTROL AND DATA ACQUISITION (SCADA) FUNCTIONS OF SUBSTATIONS AND SWITCHING STATIONS
- REMOTE ALARM SYSTEMS
- AUTOMATIC GENERATION AND CONTROL (AGC)
- TELEMETRY
- PILOT RELAYING
- DATA
- PROTECTIVE RELAYING
- REMOTE CONTROL OF POWER PLANTS
- ECONOMIC LOAD DISPATCH
- FACSIMILE
- TELEVISION FOR SURVEILLANCE AND SECURITY
- VOICE

FIGURE II-1 - POWER SYSTEMS COMMUNICATIONS

Power Line Carrier is used where the number of communications channels required is small - typically, one to four channels. It has the advantage of using the transmission resources inherent to the power system - the phase conductors.

1. Introduction

Power Line Carrier facilities are used primarily to provide borrower-owned communication services for power system operation. On large power systems it is not possible to provide the communications needs using power line carrier because of the limited frequency spectrum. Communications over power lines are accomplished by superimposing carrier frequencies on the phase conductors in a manner similar to that used on open wire telephone lines.

Figure II-2 illustrates the various types of signals that traverse the power system. It is important to note that certain of the information conveyed in a power system communications network is bi-directional, and therefore requires two way transmission. An example is that of voice communications used for operations, maintenance, and coordination control. Other types of information signals flow only in one direction. These are typically status and alarm signals which are used to either update system information or denote a change in the functional operation of the system. Control signals present in power systems are varied as to both types of signals applied and the methododology used in control. The techniques employed for control may be either quiescent, or continuous, or some combination of both. In the quiescent mode of operation, the device or function to be controlled is either inactive or unenergized until either activated by a command, or an event occurs, whereas, in a continuous scan mode, each function, device, or station is continuously scanned in sequence. Older systems generally used the quiescence mode, while the newer, computer controlled systems use the continuous scan mode. REA borrower systems may or may not have all of the operating elements shown in Figure II-2. Some function as generation, or transmission facilities, while others are distribution cooperatives only. Cooperatives may also own both generation and transmission facilities, and others, transmission and distribution. This is important from the standpoint of control. In any case, the types of signals and the flow of information discussed herein, is, for all intents and purposes,the same.

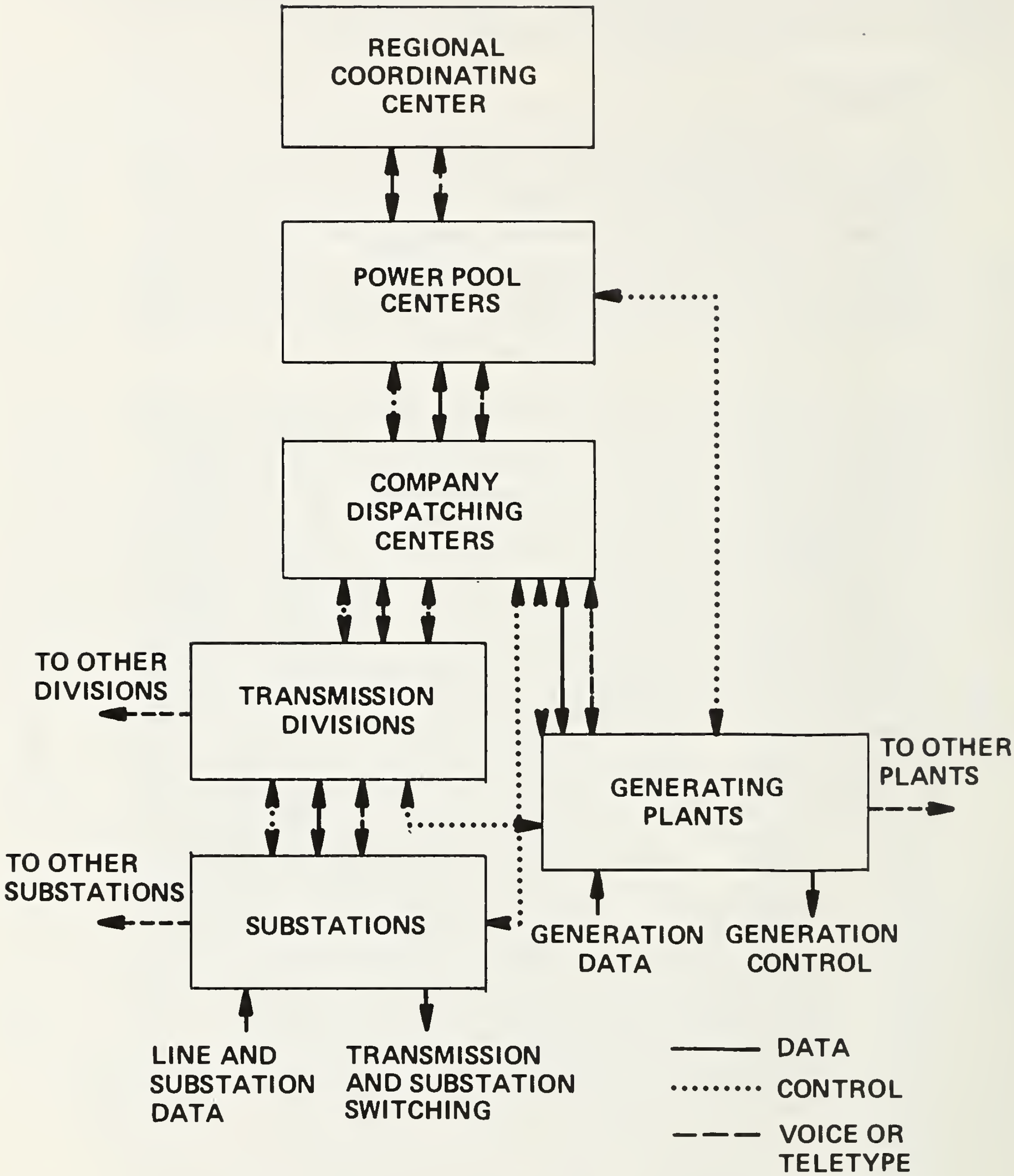


FIGURE II – 2 POWER SYSTEMS COMMUNICATIONS

2. Power Line Carrier System Characteristics

Carrier current is the technique by which low frequency radio currents are propagated over metallic conductors. Carrier current utilizes wire lines, cables, power lines, or any other metallic circuit capable of propagating this type of energy.

a. Carrier on Overhead Lines

The use of three-phase, high-voltage transmission lines as the propagation medium for carrier current is called Power Line Carrier (PLC). High-voltage transmission lines are very sturdy and use large conductors with generous spacing, providing highly reliable and low-attenuation paths for the power line carrier signals. There is a similarity between PLC and two-wire telephone transmission systems, even though different propagation conditions are encountered, due to the three power conductors, and sometimes, one or more ground wires.

Frequencies in the range of 30kHz-300kHz have been employed for power line carrier purposes, as this frequency range is high enough to be isolated from the 60Hz power frequency and from the noise that it creates, yet not so high as to encounter excessive attenuation.

The primary difference between electric power transmission and power line carrier transmission is the frequency of its operation. Although the fundamental principles of both are the same, many factors of primary importance at carrier frequencies are negligible at power frequencies. For example, the power circuits are electrically short at power frequencies (a fraction of a wavelength), and therefore, are susceptible to approximate solution, while the same circuits at carrier frequencies may be electrically long (many wavelengths), due to the higher frequencies involved.

Another important difference between power and carrier transmission is their relative efficiencies. Losses in any transmission circuit are made up of resistance and leakage losses or, as they are sometimes called, series and shunt losses, respectively. In most power transmission lines, the leakage losses in the absence of corona are small, and efficient transmission is achieved by using high voltage and low current. This is readily accomplished since most lines are electrically so short that the impedance is governed almost entirely by the step-up and step-down transformers and the associated load at the receiving end.

A Power Line Carrier System includes the signal path from the transmitting equipment at the circuit end through its tuning and coupling equipment, over the power line, to the distant end tuning and coupling unit and into the receiving equipment. Figure II-3 illustrates one such concept of the transmission of a carrier signal. The function of confining the carrier signal to the desired path and excluding unwanted signals is performed by the line traps, coupling capacitors, and tuning units to provide high impedance blocks in the undesired paths, and low impedance paths in the desired directions. Figure II-3 shows a typical PLC configuration using phase to ground coupling.

A transmitted signal from one end passes through a tuner which, in conjunction with the coupling capacitor, provides a low impedance path between the transmitter and the line. The tuner contains an impedance matching transformer, so that the electronic equipment and the line interface with the proper impedance. The line trap provides a high impedance at the channel frequencies to prevent loss of the carrier signal power into the low impedance of the station bus. The distant end line traps and equipment shown perform a similar function. A PLC channel may also consist of power cables in series with overhead power lines or insulated static wires used as a transmission path. Various coupling schemes are available and used in conjunction with different combinations of equipment to satisfy the overall transmission requirements of a PLC channel. Examples of these other arrangements are given throughout this bulletin and are explained in detail in section II-E of this chapter.

The user or subscriber equipment at the terminal end may be protective relaying equipment, telephone, data, and supervisory control channel media.

b. Carrier On Power Cable

It is possible to operate carrier facilities on high voltage power cables if due consideration is given to the fact that both characteristic impedance and attenuation are quite different from that of overhead power lines.

Each conductor in a power cable is enclosed in a grounded metallic shield. This provides two important advantages. First, the characteristics of each phase are essentially independent, i. e., not vulnerable to

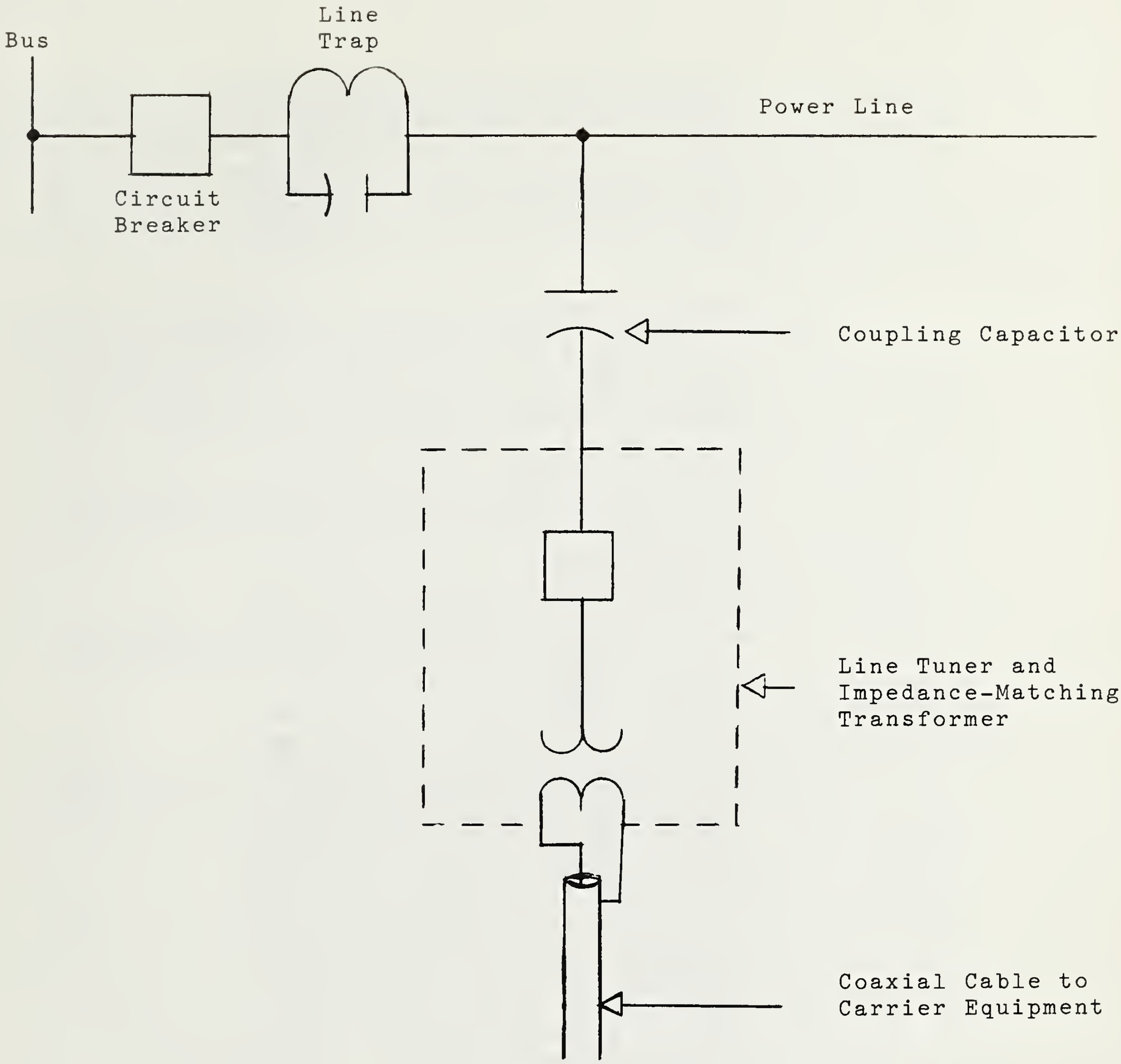


Figure II - 3

Elements of a Typical Coupling Circuit

the problems caused by uncoupled phases on overhead power lines. Second, cable conductors are not exposed to the same sources of noise that plague overhead power lines. In fact, the noise level is usually so low that carrier-receiver gain is not limited beyond that determined by inherent noise in the receiver itself.

Coupling to power cables is usually made on a phase-to-ground basis. The range of characteristic impedance of various types of cable is in the order of 25 to 50 ohms, and attenuation is approximately ten times the decibel value of that on overhead lines.

These figures are approximations which may be used as a general rule or guide. Actual measurements should be made before operation of carrier equipment is attempted.

Because of the low impedance, carrier-channel bandwidth obtainable with conventional coupling facilities is highly selective, compared with that of overhead lines.

In some power systems, relatively short lengths of power cable are occasionally used to provide underground entrances for overhead power lines. A carrier circuit on the overhead line may be operated in several ways. If space is available, and if the location is a true terminal point, the carrier transmitters and receivers may be located at the transition point and the services extended into the main substation by means of audio cable. A second method is to install coupling facilities on the overhead line and bypass the carrier frequencies into the substation via coaxial cable. A third method is to install coupling facilities on both the overhead line and the cable so that impedance-matching facilities may be installed at the transition point. The fourth method is to permit the direct connection of the carrier circuit from the overhead line to the cable. Only rarely, however, will this last method provide enough efficiency for satisfactory operation because of the extreme impedance mismatch which will exist. A choice among these methods will depend upon the length of cable involved, the required bandwidth of the carrier channel, the importance of the carrier services, and the amount of reserve signal that is available.

A representative attenuation range for power cables is shown by the solid curves in Figure II-4 , for a single phase-to-ground feed. Since coupling between phases in a three conductor pipe-type power cable decreases at lower frequencies, interphase coupling appreciably decreases the attenuation shown in Figure II-4.

c. Power Cables Combined With Overhead Lines

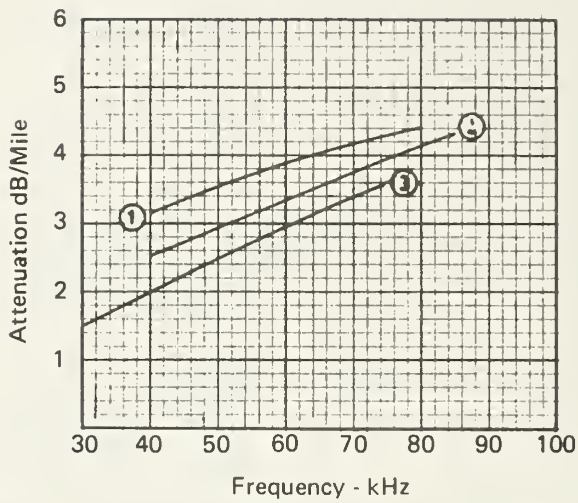
In applying Power Line Carrier to circuits involving a combination of overhead line and power cable, limitations are due to three principal factors: (1) the relatively high attenuation of the cable portion, (2) a series impedance mismatch at the junction due to the impedance difference between the characteristic impedances of the line and the cable, and (3) the added losses due to standing wave reflections from the junction point, together with wide difference in mode of propagation between the line and the cable.

Power cables offer a very reliable communications medium because of their rugged, high voltage construction. Applications of discreet carrier frequencies on shorter circuits of mixed facilities are usually practical because the losses encountered can be absorbed in the electronic equipment operating range. Wideband applications of carrier on mixed facilities are generally not practical because of the variations of characteristics with frequency. However, single-channel SSB applications are often feasible. In cases where the power cable portion has excessive attenuation, as in cables with cross - bonded sheaths, a communication cable bypass of the power cable may be required. Bypassing either the overhead line or cable portion eliminates the problems associated with the junction point, but care must be exercised that the communications cable is not damaged due to induced voltages, or difference in ground potential during system faults.

Magnetic shielding of the communications cable bypass is advisable if the location is in the flux-field of high current power circuit.

Carrier transmission losses in power cables vary a great deal, depending on the construction of the cables.

Single-Conductor Types: Single-conductor power cables



① 138 kV, 1250 MCM, 1 Copper Skid Wire, Pub. Ser. Elec. & Gas N. J. Test on 10.9 Mi.

② 138 kV, 1250 MCM, 2 Copper Skid Wires, Pub. Ser. Elec. & Gas N. J. Test on 10.9 Mi.

③ 345 kV, 2000 MCM, Consolidated Edison Co.
Test on 15 Mi & 18.3 Mi.

Figure II - 4 Pipe-Type Cable Attenuation Curves

with solidly grounded sheaths exhibit reasonably low transmission losses, and usually are satisfactory for carrier applications. For estimating purposes, the carrier attenuation values for RG-8U cable may be used to determine the losses for single-conductor power cable with solidly grounded sheaths.

Single conductor cables with cross-bonded sheaths or transformer-bonded sheaths are not suitable for carrier circuits.

If a carrier is coupled to single conductor cable with cross-bonded sheaths, a new sheath is introduced at each sheath junction, and this produces a high loss due to the multiple paths. If sheath-bonding transformers are used, the inductance of the sheath-bonding transformer causes high loss to carrier frequencies. By-passing of these transformers has been tried without success.

Pipe-Type Cable: With this type of cable, the carrier transmission loss varies with the type of construction of the shielding tapes used on each individual conductor. In order to reduce 60Hz losses, these tapes are very thin (5 mils) and are spirally wound around the cable insulation along with a paper tape which insulates the turns of the shield tape. In order to protect the cable as it is pulled into the pipe, two or three skid wires are wound in a long pitch spiral around each cable on top of the shielding tape and these skid wires provide the carrier return path.

The surge impedance of the cable is a function of the conductor size and the insulation thickness.

Losses due to series mismatch are experienced when an overhead line is connected to a power cable. Particular emphasis should be placed upon determining these losses.

In such applications, the losses at each such junction may be calculated by the equation:

$$\text{dB Loss} = 20 \text{ Log}\left(\frac{Z1 + Z2}{2\sqrt{Z1 \times Z2}}\right)$$

where: Z1 = impedance of the overhead line
Z2 = impedance of the power cable

Signals transmitted into the overhead line toward the cable portion are subject to cancellation and reinforcement due to standing wave reflections from the junction point to the coupling point. Frequencies to avoid can be determined from the familiar frequency vs. wavelength formula used for antenna calculations. From the overhead line end, when the line portion is short, the input impedance varies widely with frequency

Since the overhead line involves several multiples of $\lambda/4$ or $\lambda/2$, the input impedance does not swing between quite as wide limits because of attenuation of the reflected wave. When the overhead line attentuation is 3-5 dB or more, the reflected wave has little effect on the input impedance to the line and this impedance only varies slightly around the normal characteristic impedance of the overhead line. In this situation, there is no need to avoid certain frequencies as outlined above.

The full wavelength for the frequency under consideration may be calculated from the following formula:

$$\lambda = \frac{(186.3)\ \ (V.P.)}{f}$$

Where λ = Wavelength in miles
f = Frequency in kHz
186.3 = Constant
V.P. = Correction Factor if propagation is less than speed of light (in per unit)

For overhead lines, a V. P. factor of 0.98 per unit may be used in calculations. For example, the $\lambda/4$ and $\lambda/2$ distances based on this formula are:

f	$\lambda/4$Distance	$\lambda/2$Distance
25	1.828 mi.	3.656 mi.
50	.914 mi.	1.828 mi.
100	.457 mi.	.914 mi.

The best practice at this time is to avoid frequencies corresponding to $\lambda/4$ and $\lambda/2$ because of the wide departure of the input impedance from the normal characteristic of the overhead line.

Frequencies should be chosen that are in between these

two points and multiples thereof. Special coupling arrangements will help solve the $\lambda/4$ and $\lambda/2$ cases on a single-frequency basis. The majority of applications involve at least two frequencies: one frequency for line protection, and one for transfer trips which utilize two-frequency line tuners. If the two impedances seen at the separate frequencies are not too widely different in value, careful selection of line tuning components as to high or low impedance types may help to achieve a workable application.

Other factors affecting signal transmission and coupling to the line are discussed in later sections of this bulletin, as appropriate.

d. Transmission Line Characteristics

In the transmission and propagation of virtually any signal, the transmission media is the deciding factor as to the behavior and structure of the resulting signal. A power transmission line is both unique and complex because of the effect that it imparts on the carrier frequency signals. These effects must be ascertained since they are the determining factors which define the overall transmission line characteristics.

Power line attenuation is influenced by several variables to one degree or another, among which are: carrier frequency of propagation, method and type of construction, line voltage, conductor size, presence of ground wires and taps, coupling method, weather conditions, and transpositions.

Power transmission lines are subject to a wide range of weather conditions that affect the circuit quality. Attenuation of a signal will increase as much as 10dB under high temperatures, wet weather, frost, icing conditions, and lightning will cause noise levels to increase up to 15dB. Moisture and ice also cause variations in the shunt capacitance of the phase conductor. Accumulated dirt and dust on the insulators become conductive and increase the line attenuation during wet weather. (Figure II-39shows the effects of both fair and adverse weather. For facility in usage, these values are referred to as3kHz bandwidth, and will be used in section 2 H, Engineering Calculations, to determine the resultant signal-to-noise (SNR), in the message channel).

The characteristic impedance, or surge impedance of a phase conductor to ground is characterized by the mechanical configuration of the power line. The Z_c as defined previously, is the ratio of voltage and current of the traveling wave on a line of infinite length. This ratio, at any point, is a constant, Z_c. Also, in common practice at power line carrier frequencies, the quantics $j\omega L$ and $j\omega C$ are large compared with R and G, so that the latter can be neglected, and the characteristic expression for impance can be reduced to:

$$Z_c = (L/C)^{1/2}$$

Applying conventional formulae for L and C above yield:

$$Z_c = 276 \text{ ohms} \log_{10} \frac{D}{r}, \frac{D}{r} > 20$$

where

D = the distance between conductors, and

r = the radius of the conductors

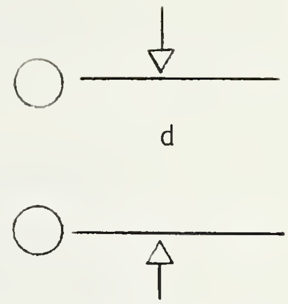
The above equation is for two conductors. For a single conductor of distance h above the ground, and radius r, the characteristic impedance is:

$$Z_c + 138 \text{ ohms} \log_{10} \frac{2h}{r}$$

In the case of bundled conductors, the geometric mean radius (GMR) is used for r in the above equations. Figure II-5 shows the GMR for 2-wire, 3-wire, and 4-wire bundled conductors. The calculation of impedance for a three-phase transmission line is complex, and further complicated by the use of bundled conductors. A transmission line terminated in it's characteristic impedance will reflect no energy from the termination and may be considered infinitely long. From the above, it is seen that the characteristic impedance is based on the diameters of the conductors and the distance between conductors. Both dimensions will increase with higher voltages, and therefore the ratio will tend to remain constant. Lower values of characteristic impedances will exist on EHV transmission lines since the bundled conductors are used which have an effective radius much larger than the radius of a single conductor. The characteristic impedance of power cables will be in the range from 25 to 50 ohms.

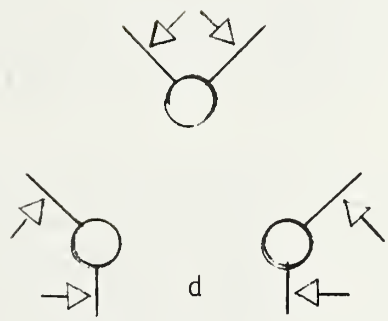
FOR 2 WIRE BUNDLES

$$GMR = \sqrt{10^{-.25\mu} r d}$$



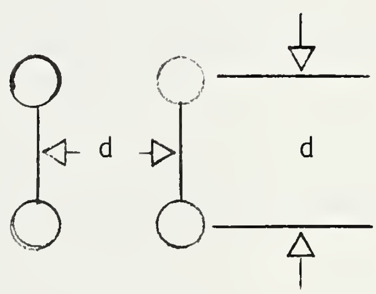
FOR 3 WIRE BUNDLES

$$GMR = \sqrt{10^{-.25\mu} r d^2}$$



FOR 4 WIRE BUNDLES

$$GMR = \sqrt{10^{-.25\mu} r \sqrt{2}\ d^3}$$



r = Radius of Individual Conductors

μ = Permeability of Conductors

Figure II - 5

Bundled Geometric Mean Radius

Table II-1 below shows the range of Z_c for power line carrier circuits on overhead lines.

Table II- 1

Transmission Line Conductors each phase	Z_c in Ohms	
	Phase to Ground	Phase to Phase
Single Wire	350-500	650-800
Bundled (2 Wires)	250-400	500-600
Bundled (4 Wires)	200-350	420-500

When a carrier frequency is applied to a three-phase lower line, the energy proceeds down the power line in the same manner as a 2-wire communications circuit. In the case of three or more conductors, the self and mutual impedance provide conditions of mutual coupling and permit the power to be interchanged and distributed among the various conductors.

On multi-conductor power lines attenuation increases as a linear function of frequency at higher frequencies. Lower voltage lines have smaller conductors with higher resistance and attenuation per unit of length. Transmission lines in the 300 to 500 kV range usually have bundled conductors with lower resistance at carrier frequencies. The spacing and height of power transmission lines is such that induced carrier frequency current flows in the earth, even in the case of interphase component signals. The magnitude and the resulting carrier attenuation are functions of conductor spacing to height and ground resistivity.

Transmission losses range from 0.10 to 0.55 dB per mile for transmission lines ranging from 14 to 500kV

Transpositions of power lines cause additional losses to carrier frequency transmission. Losses may be expected to be 6dB or greater for lines having five or more transpositions. Furthermore, the variations in spacing of transpositions manifests itself with losses of around3 dB for closely spaced multiple transpositions versus a loss of 6 dB for a single widely spaced transposition of 80 miles or more.

Data and voice communications requirements are different in their application on power line carrier circuits. Data transmission requires careful consideration in the configuration of the PLC facilities.

3. Insulated Static Wire System Characteristics

Throughout the United States, in areas where lightning activity is extensive, normal construction of high voltage power transmission lines include "ground", or shield wires strung over the power carrying conductors throughout the transmission system. These wires are positioned in this manner to protect the transmission lines from lightning strikes. These wires are normally grounded to each tower or pole throughout the entire transmission line system, and under these conditions, are not used for communications transmission.

In instances wherein these wires are to be used for the transmission of communications, in addition to the protection from lightning feature, this can be accomplished via insulation of the ground wires. By insulation of the wires from the towers or poles with relatively low voltage insulators (approximately 15kV) an effective insulated static wire system results which can be used for the transmission of desired communications, and which will also provide lightning protection.

Since the insulated wires are subject to high power frequency induction, connection of the carrier transmitter/receiver equipment to the insulated static wires by appropriate line protection facilities at the terminals of the system is required.

A typical coupling arrangement for interconnecting an insulated static wire circuit with the carrier terminal equipment is shown in Figure II-6.

It should be pointed out that insulating the shield wires causes a slight increase in the zero sequence impedance of a power line circuit which can cause a corresponding increase in overvoltages associated with line-to-ground faults. In most systems this increase can be neglected; however, in systems with high ground impedance this increase may be significant.

The cost of coupling equipment for an ISW circuit is less than that for PLC coupling, since PLC equipment used on phase conductors requires coupling capacitors, and wave traps, whose costs increase substantially at higher transmission line voltages.

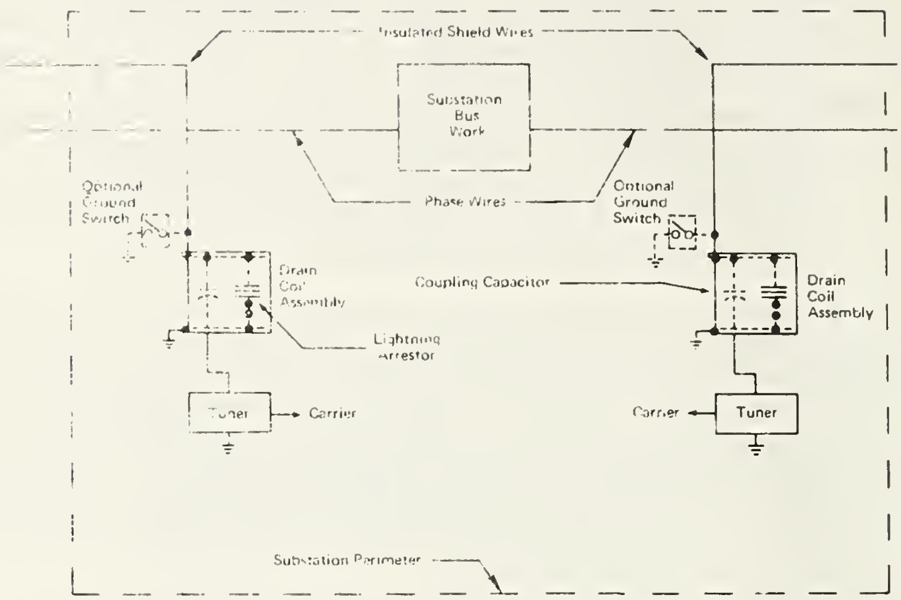


Figure II - 6 Recommended Physical Location of Shield Wire Conductors

In contrast, the cost of ISW coupling equipment remains relatively constant as a function of system voltage. Maintenance costs are lower because practically all maintenance work on both line and terminal equipment can be done without de-energizing the transmission line. No line outages are required for changing frequencies of carrier terminal facilities or adding new facilities to the insulated ground wire channel.

Noise on insulated ground-wire circuits is maximum at low frequencies. On most circuits the noise level is prohibitive at frequencies below approximately 5 kHz. Although in some cases, more frequent transpositions may allow limited carrier operation down to 3 kHz. At carrier frequencies a balanced ground-wire circuit has noise advantages over phase-to-ground power-line carrier.

A carefully designed insulated ground-wire pair will have a useable bandwidth from about 5kHz to well over 450kHz. Standard open-wire telephone-line carrier equipment, including repeaters, can be used quite satisfactorily if attenuation and noise limits are considered in the application. Standard power-line carrier equipment, which normally operates at higher output levels may also be used. Most of the transmitters used currently have one watt or greater power output.

Under line fault conditions, or in the event of a lightning hit, the noise induced into the shield may be considerably higher for the duration of the line fault, depending upon the level of insulation used. For this reason the use of protective relaying is not recommended over ISW. Voice, supervisory control (depending upon the function contemplated), alarm and telemetry signals may be used on ISW circuits as they would on PLC over phase conductors.

Losses and noise levels, frequency allocation, and dual shield wire coupling are discussed in latter sections of this bulletin.

a. Insulated Static Wire Vs Phase Conductor

Although history of usage of insulated static wire for carrier communications is limited, definite advantages have been noted in its utilization, which make it more desireable as a transmission medium than phase conductors. The main advantages realized are in the area of coupling facilities, and related costs and bandwidth.

The frequencies between 12 and 50kHz are normally unavailable for use on phase wires due to the large size of the coupling capacitors and line trap inductance required to couple these low frequencies onto the line. Thus, the cost of these large units negate the use of these low frequencies except for narrowband, single function relay applications. Therefore, by using the insulated static wire techniques, smaller coupling units are available at a lower cost, and a greater overall bandwidth is realized.

As pointed out above, use of the insulated static wire include: lower maintenance costs, since practically all maintenance can be performed without disengaging the transmission line; and, no line outages are required for changing frequencies of the carrier terminal facilities or the adding of new facilities to the insulated static wire channel.

The major disadvantage with the insulated static wire is that more momentary interruptions are likely to occur because the ground wire insulators will flash over on lightning discharges and fault current induction. Experience indicates however, that services such as telemetering, telephone, and supervisory control should be entirely satisfactory.

Lightning flashovers of the shield wire insulators will cause the attenuation to increase from 1 to 8dB, lasting for about a millisecond. Flashovers which accompany a power line fault will last until the fault is cleared - typically about 60 milliseconds, or longer. The increase in attenuation will also be higher depending upon the number of phases and other factors involved.

During wet weather an allowance should be made for approximately 20 percent increases in attenuation. Insulated shield wires are also more susceptable to losses due to frost than phase wires as they do not have a significant amount of current induced for self-beating. Additionally, ice bridges may form over the relatively small insulators.

b. Insulation

Several different types of insulators may be used. For example, a 15kV guy strain insulator of the fluted type has proven to be suitable. The insulator, along with two strain clevises at each point of suspension,

provides a reliable arrangement in that the ground wires cannot fall down onto the phase conductors if an insulator is broken. The flashover voltage of the 15kV insulator is approximately 32kV. In current practice, arc gaps are ordinarily added to provide a lower potential flash-over and to prevent scoring of the insulator glaze with repeated lightning strikes.

Other satisfactory insulators in use include pedestal and higher voltage types. Insulator flashovers ranging from 7.5 to 20 kV may be used depending upon the type of line construction and the characteristics of the signal to be transmitted. The smaller the insulator flashover voltage level used, the longer the duration of high noise level will be maintained after a disturbance because of damage to the insulators.

c. Conductors

The conductors used on an overhead insulated shield wire channel may be either steel, copper, or bi-metal cables. The characteristic impedance of a single overhead insulated shield wire is approximately 500 ohms, whereas a balanced pair configuration has a characteristic impedance of about 900 ohms.

Steel shield wires have the highest dB/mile attenuation factor of all types available. The high attenuation factor does negate their use on long lines, but there are many cases where satisfactory communications exist over steel shield wires on short line sections.

Aluminum clad steel conductors and copper shield wire have the lowest attenuation factor, and thus provide the most useable communication medium for both short and long line sections.

Attenuation on insulated ground-wire circuits varies widely, depending largely on the conductivity of the wires, and to a much lesser extent on line dimensions, proximity to phase conductors, transposition intervals, and line length. For estimating purposes, conductors with different resistance per unit length should cause attenuation of proportionate magnitude. Limited experience indicates losses on a single wire with ground return to be approximately 50 percent higher than that on a balanced pair.

Usually, shielded transmission lines designed for 115 kV or higher use two ground wires, while in some cases

lower voltage lines use only one. While one insulated ground wire can be used for carrier communication, the two wires used as a pair have definite advantages in noise and attenuation. If the ground wires are to be used for carrier communication, it may be economical to use higher conductivity wires, depending on the length of line and type of carrier equipment proposed.

d. Transpositions

As a result of the contiguity of the insulated static wires to the phase conductors, the insulated static wires are subject to induced voltages from the power lines. Transposition is a method of minimizing this interference by interchanging the position of the power line. To be effective, each pair of conductors must be transposed at electrically short intervals for noise reduction.

The primary aim of a transposition scheme is to provide balance of power-frequency influence so that induced current in the two wires will be equal and in phase. However, proper transposing will also reduce the magnitude of drainage current flowing in the ground lead of the terminal protectors by a proportion depending on the power conductor configuration.

A transposition scheme would take into account any change in the uniformity of the line, such as closely paralleling transmission lines for more than a few hundred feet or a change from single-circuit to double-circuit tower construction. Transpositions should be located so that the power-frequency induction is balanced out independently in each uniform section of the transmission line. Thus, the number of transpositions in any particular line will depend upon its uniformity.

Transpositions are usually made by the "point" method. That is, on a relatively long uniform section of the system lines, at a one-quarter or three-quarter point, or on relatively short lines, at mid-point only. At these points, the insulated static wires are dead-ended on a structure, with cross connections made on pin-type insulators. In this manner, the static wires always remain parallel to each other, except at the cross connect, or transposition insulators.

The maximum distance between transpositions will be determined by how much voltage can be tolerated in the

shield wire during periods of heavy power line loading. Typically, this distance ranges between 10 and 48 km, depending upon line voltage, current, and borrower experience.

B. Systems Considerations:

During the conceptual phase of any communications system, it is necessary to evaluate the various postures which the final system may assume. This is often referred to as the planning phase, a phase which generally consists of three major segments:

- Developing the Requirements
- Establishing a basic concept, and
- Detailing a communications plan

Only after the execution of these plans has been accomplished can a procurement specification be written and subsequently released to communications system vendors. The premature preparation or release of the communications specification will manifest itself at a later date in the form of change orders. These change orders have a tendancy to change the final cost of the negotiated procurement, not to mention perturbations of the form, fit, and function of the procured system. This section provides an overview of the functions and considerations involved in the execution of the planning phase.

1. Developing the Requirements

This may be a formal procedure, documented by a staff study, or informally documented by a memo. The initial step in establishing the system parameters is the interpretation and translation of the basic communication needs into a realistic and feasible definition of the system requirements. This initial step is provided by concise statements to the items developed in Table II - 2, which provide an analysis and substantiation of the requirements. The analysis must necessarily consider the merits of competitive approaches. If, for example, an existing cable or microwave line-of-sight system can be extended and updated practically and economically, to fill the requirement, the planner is required to recommend consideration of this alternative.

During this initial step of the project definition, broad guidance is needed to permit the planner to determine rapidly the most appropriate and cost effective means of transmission, taking into consideration the distance, routing, and number of channels required to satisfy the new or additional communications requirement.

Table II - 2

Development of Requirements

Items Considered	Elaboration
Purpose of System	Statement of communications requirements that this system will satisfy, which are not satisfied, or only partially satisfied by the existing system
Impact of Proposed System on Overall Communications	Consider budgeting requirements and the competing alternatives for the same funding. Consider the impact of the proposed system on other existing or proposed systems that it will interface, replace, or partially duplicate
Long Range Effect of the Proposed System	Optimum utilization of the proposed system may require that related facilities be designed; if so, this should be pointed out. The potential of the system for growth or modification to meet changes in requirements should be developed also.

2. <u>System Concept</u>

When the requirements have been analyzed and defined a system concept is developed that will meet the needs of the prospective communications users. Factors that must be considered and the steps to be followed in establishing the concept are shown in Figure II - 7.

The system concept in the planning stage is sufficiently simple that it may be depicted in a single line drawing, on which all known information is noted.

The feasibility surveys, following the development of a preliminary system concept, considers such aspects as is location "A" or "B" the most appropriate choice, or, are any of the routes selected impractical to achieve?

The information shown below is indicative of the information to be gathered and analyzed. It should be noted that much of this information will be of a preliminary

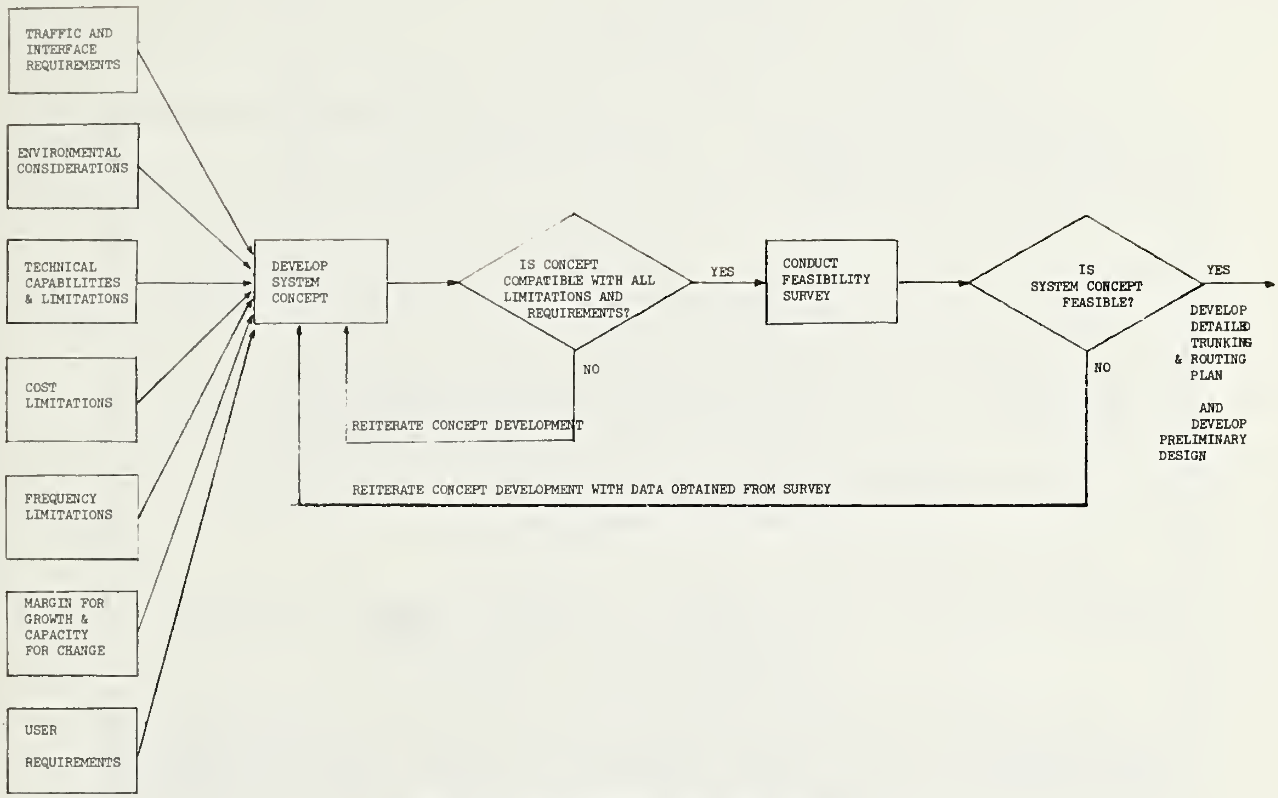


Figure II-7 Establishment of A Basic System Concept

nature, and will not be determined in a specific manner until several iterations of conceptual planning have taken place. The elements of PLC planning are shown in Table II-3.

Table II - 3

PLC Planning

Items Considered	Elaboration
Develop Data Base	Denote existing frequencies used, the services provided, and details of existing equipment
Coordination	Coordinate existing carriers and ascertain available frequency spectrum
Transmission Path	Determine adequacy, switching, and weather conditions
Coupling Configuration	Predicate a coupling method considering: coupling efficiency, propagation, reliability, and economics
Communications to be Provided	Ascertain need for single vs multi-function carrier considering: number and types of services, line length, noise level points of simultaneous transmission, priority of services, repeat and drop requirements, reliability and redundancy, spectrum utilization, plus economics
Transmission Line Parameters	Establish type of line, line voltage, each section of line length, transpositions, tapped lines, alternate routes type of conductors and ground wires, line noise and attenuation data, and supply voltages

3. Preliminary System Configuration

The steps in developing the preliminary system configuration and the resulting output documentation are shown in

Figure II - 8

The first step in preliminary system planning is to develop a system trunking plan based upon approved user requirements. This system trunking plan will provide, in line diagram form, a layout of system channel requirements and terminal locations. The steps involved in developing a trunking plàn are best conveyed by an example. Figure II - 9 sample trunking plan and Table II - 4 presents its circuit requirements. For simplicity, only voice and teletype requirements are shown. Teletype requirements are also translated into equivalent voice channel requirements on the basis of multiplexing (combining) 12 teletype channels into 1 voice channel.

The system trunking plan uniquely defines the routing and portrays the system layout in terms of a definitive system configuration. The preliminary design and costing of the proposed system, based upon a definition of the user requirements, may now be executed. The factors bearing on the overall system design are discussed in II - C.

Table II - 4

Sample Circuit Requirements

Between Stations	Voice	Teletype	Voice Equiv. to Teletype	Total Voice
A - B	2	6	1	3
A - H	2	9	1	3
B - C	1	12	1	3
B - H	1	14	2	3
C - D	2	6	1	3
C - F	3	7	1	4
C - G	1	9	1	2
D - E	1	10	1	2
E - F	2	11	1	3
F - H	1	13	2	3
X - Y	3	17	2	5

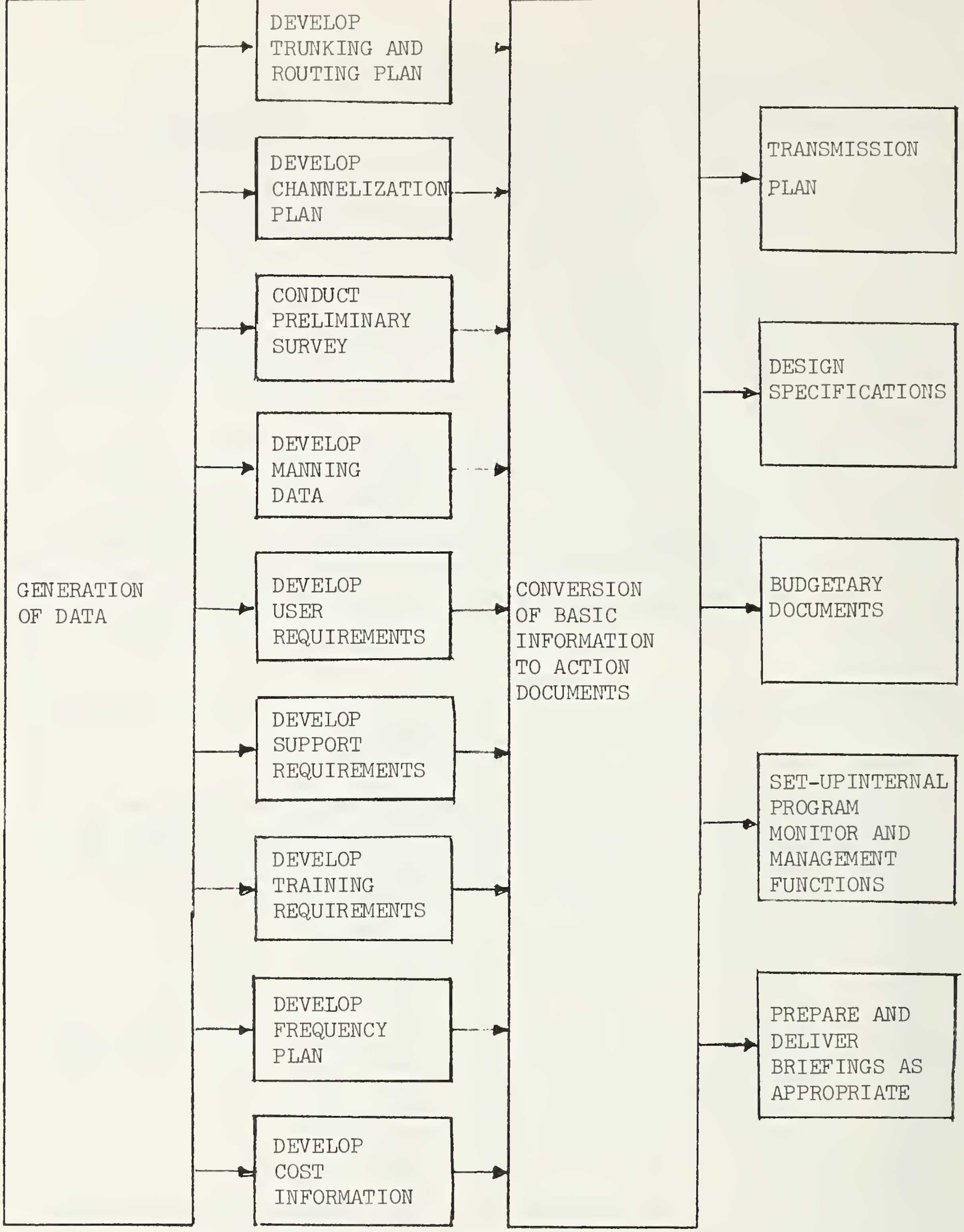


Figure II - 8 Detailing The Plan

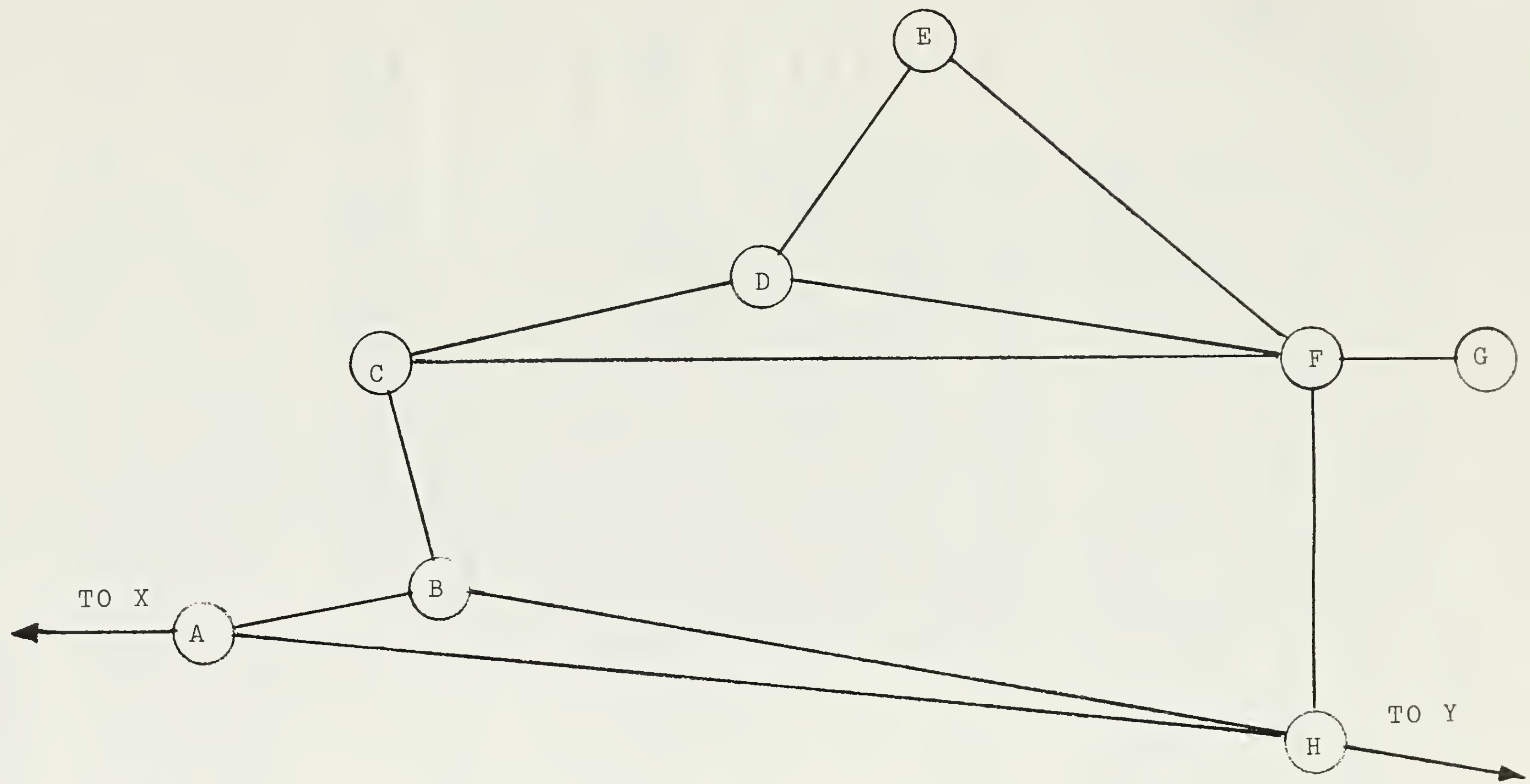


Figure II - 9 Trunking Diagram

C. Design Considerations:

The basic concept of systems planning involves a thorough investigation of the pertinent design factors, their limitations and constraints as they bear upon the total communications design. The subsequent sorting, culling, examination, and analysis of the design parameters will yield the preliminary design. The final design, if everything has proceeded according to plan, is, or should be, a fine tuning of the initial design. Without such procedures, we may end up with communications between or among users which neither serve their needs, nor meet their design requirements. The overall design considerations involve identification and resolution of the following:

- Who needs communications?
- What are the types of communication services needed?
- Are there presently communications between or among the potential users?
- What types of transmission lines are available to serve the facilities to be connected?
- What are the transmission considerations involved?
- What are the characteristics of the carrier transmission circuit?
- Is coordination of existing carrier required?
- Are both single and multi-function carrier services required?
- What are the constraints on frequency spectrum utilization?
- Are there any unique applications of service to be considered?
- What are the equipment applications and factors to be considered?
- Is acclimatization of facilities required?
- Is the proposed design the most economical and viable solution to the stated requirement?

The discussion that follows will highlight some of the considerations necessary to resolve the above questions. It will not provide the requisite detail to answer these questions--that is, the purpose of the balance of this bulletin. Rather, this section is designed to serve as a compendium for the thought process involved in the review and analysis of the design considerations.

1. Route Engineering

In the preliminary planning stages, the systems engineer

lays the groundwork for the proposed system. Investigations are conducted to determine the locations which must be connected by the proposed system, the number and types of communications circuits required between various locations and the possible need for interconnecting the system with existing communications facilities. Based on the data compiled, a preliminary route map is prepared which indicates the geographic locations to be linked by the proposed PLC and/ or ISW system (s). Among the questions to be answered is the communications hierarchy. For instance, will communications be governed by a centralized dispatch center? Are communications required between or among distribution members, sub stations, transmission divisions, and generation facilities? Another aspect that should be taken under consideration is future expansion involving power pool centers under control of a regional coordinating center. Finally, it may be that future communications systems will have to be designed on a master plan basis similar to modern housing developments.

2. Communications Services Required

From the outset this is perhaps one of the most important functions in the design process. First the designer must consider the various modulation formats available. The types of signals which PLC or ISW systems may consist of are: Amplitude Modulation (AM), Frequency Modulation (FM),Single Sideband (SSB), Frequency Shift Keying (FSK), and Keyed Carrier. The particular modulation format selected will depend upon the carrier function to be selected from among:

- Voice
- Telemetering and control
- System Protection

Voice communications may either be:

- Simplex (one-way)
- Duplex (two-way)
- Speech-Plus (the sharing of voice channel with other services)
- Multi-channel (more than one voice channel per line segment or several voice channels over a line segment)

Telemetering and control systems may consist of:

- Remote Alarm Functions
- Analog telemetering
- Digital signals

- Automatic Generation Control (AGC)
- Supervisory Control and Data Acquisition (SCADA)

System protection applications involve:

- Pilot Relaying
- Equipment Protection
- Line Protection

By way of retrospect, if a single modulation format were to be considered as serving power systems communications from the best advantage, Single Sideband (SSB) would most nearly meet that requirement. SSB offers:

- Higher Quality Voice Circuits
- High Speed Data Capability
- Frequency Spectrum Conservation

Functionally, a single voice channel of 4kHz bandwidth may be used in any one of the following configurations:

- One voice channel plus one relay channel or one data channel (300-2400 B/S)
- One voice channel plus six telemetering functions, or one data channel (600 B/S)
- One voice channel plus one blocking/relaying channel
- One voice channel plus one transfer-trip signal
- One transfer-trip signal plus one blocking/relaying signal

These are but a few of the possible configurations available for the designer's consideration, however, they can only be determined once the requirements are set forth and a subscriber survey is performed. A subscriber survey involves the determination, by actual physical inspection, of sufficient data on the location and services needed for each user (subscriber) in the system.

3. Existing Communications

If a communications system exists between and among the facilities to be served, several considerations arise. Expanding an existing system without need for further growth is relatively simple.

Existing communications facilities present several difficulties and challenges to the designer - the effects of

expandability, age and frequency utilization. Care must be taken to determine the effects of possible transmission impairments to overall system performance as a result of equipment aging. The extent to which equipment was maintained will have a bearing upon replacement or refurbishing the existing equipment. Consideration will have to be given to the possible interruption of existing service during the new system cutover. Transpositions and their effects on the system design will have to be ascertained. Finally, the designer may be faced with the decision to replace the entire existing system if key technical problems cannot be overcome. In fact, it may be both economically and technically the most feasible alternative.

4. Transmission Line Considerations

The transmission line and the static wire are the transmission mediums for PLC and ISW communications systems, respectively. As such, they form the most important elements of the system. They give excellent service, but are very complex to analyze and as such, their characteristics must be both recognized and analyzed. The primary factors to be considered are among the following:

- Weather effects
- Impedances
- Attenuation
- Carrier frequency response
- Transpositions
- Intermediate line taps

Attenuation effects due to adverse weather varies from 10 to 20 dB. Shunt capacitance is also influenced by moisture and ice. Accumulated dirt and dust may cause insulators to become conductive--thus affecting overall line attenuation.

Impedance relationships of both the transmission line and sub-stations are important as they affect the transfer of power in a carrier circuit. The sub-station equipment will affect the insertion loss and frequency response.

Attenuation or line losses are primarily functions of:

- Carrier frequency
- Type of line construction
- Line geometry
- Phase conductor size, material surface condition
- Ground wire size, material, location

- Method of coupling
- Type and locations of transpositions
- Weather conditions
- Ground conductivity
- Insulator leakage

On multi-conductor power lines the conductor spacing is proportionately wider than that of two-conductor telephone lines, hence, the attenuation increases more steeply as the carrier transmission frequency increases.

Transpositions on power lines are for the benefit of the power system and not communications transmission. A transposition acts as a mode converter and regenerates higher attenuation modes. A single transposition in the middle of a long line can introduce a 6dB loss. Closely spaced multiple transpositions will yield losses on the order of 3dB.

A line tap on a three-phase power line appears as an unterminated stub at carrier frequency and affects the frequency response. The stub produces a low impedance shunt across the line over a wide range of frequencies. The net effect is to increase the attenuation at certain frequencies.

5. Characteristics of the Carrier Circuit

The nature of the carrier circuit is important in that it describes: what exists, where things are, and how they are connected and interrelated. In order to arrive at the carrier circuit characteristics, a single line diagram of the system should be made showing the location of all major apparatus, line lengths, voltages, currents, etc.. We must determine:

- Locations of proposed equipment
- Function at each location
- Locations of existing equipment
- Locations of possible future equipment
- Locations of carrier bypasses
- Locations of circuit breakers, disconnect switches, buses capacitors, cables, transformer regulators, and etc.
- Lengths of carrier transmission circuits
- Lengths of directly connected power circuits
- Voltage at coupling points
- Altitude of coupling points
- Load current at trapping points

- Fault current at trapping points
- Separation distance for parallel lines
- Circuit attenuation
- Circuit noise level (if possible)
- Alternate routes

Spectrum planning involves establishing a frequency allocation plan that coordinates existing carrier frequency usage with that of the presently planned system and future allocations for expansion. Considerations must be given to move, retire, or update existing equipment. Relaying and communications functions must be integrated and coordinated for maximum use of allocated spectrum.

The determination of frequency usage will involve determining the number and types of services, analyzing routing vs line length, and noise levels, which services have priority or exalted requirements. Once these functions are determined, the use of each 4kHz channel follows.

6. <u>Unique Services</u>

Special applications involving the use of automatic baseband switching may have to be considered for certain priority circuits and audio relaying tones. Alternate path routing should be considered wherever loops are involved. Multi-path routing may be essential for communications from radial links. Block and Insert requirements will be determined in conjunction with the service offered and routing available. Hot standby protection and parallel amplifiers should be considered for critical functions.

7. <u>Equipment Applications</u>

Considerations involving equipment selection and application require the designer to:

- Evaluate the cost effectiveness
- Consider the reliability aspects and requirements
- Know the limits of circuit design for each service offered
- Evaluate the interference consideration
- Determine coupling method for:
    - Phase-to-ground
    - Phase-to-phase
    - Intercircuit
- Determine line trap parameters for:
    - Inductance
    - Trap impedance
    - Frequency band

- Determine line tuner requirements
  - Single frequency
  - Wide band
  - Double frequency
- Investigate need for,or use of,auxiliary coupling devices
  - Reactance hybrids
  - Resistance hybrids
  - Skewed hybrids
- Determine use of,or need for,isolation filters
  - Low pass
  - High pass
  - By-pass blocking

The selection of baseband or audio repeaters involves a comparison. Baseband repeaters are cheaper, have less distortion, and the loss of a channel modem will not impair through traffic. Whereas, audio repeaters provide good isolation between frequencies, they may be interconnected with types of carrier facilities, however, the loss of a channel is also the loss of a circuit.

Acclimatization may be necessary if equipment installed is to be subjected to extremes of temperature and humidity. Manufacturers' performance guarantees are affected by these parameters, and so is the system performance. Extreme conditions should be noted during the initial planning and design phase, and appropriate steps should be taken to obviate potential problems.

Economic considerations are apparent in every phase of the design of a PLC or ISW communications system. However, their considerations must not rise to a degree that performance is sacrificed. In the selection of any piece of equipment to be applied,scale factors should be developed for the important parameters and expense or cost should only be one factor among equal factors. If equal factors cannot be determined, the appropriate weighting to each factor must be applied.

D. Systems Engineering Procedures

This section develops certain of the requisite planning and engineering procedures necessary to scope the level of effort and system requirements. The constituents of the planning sequence are set forth in conjunction with determining of engineering requirements. The criteria regarding channelization and routing of signals is discussed. Aspects relating to frequency assignment and future expansion are examined.

1. Planning Sequence

The determination of the communications requirement is the first step in system design and in many instances it is the most difficult task. Since most communication system designs involve a great many factors, involving technical evaluations and cost comparisons, the importance of defining user requirements cannot be over-emphasized. The material within this section deals with the methodology involved in the overall planning function. The following fundamental parameters of system design are listed in their order of execution:

- Communications objectives - This requires the determination of who the users are, what type of information is to be conveyed, and locations of information sources and sinks.

- Traffic analysis - Traffic flow and volume are analyzed to determine route loading. Preliminary routing is established to accommodate the projected traffic flow and loading requirement.

- Design criteria - This step establishes the acceptability criterion based upon grade of service and performance desired by the user.

- Operating requirements - Determines traffic priorities, maintenance criteria, operating procedures, and service schedules (order as to necessary, essential, and/or critical).

- Facilities survey - Available services, facility status, and transmission network type and condition data are gathered.

- Vendor analysis - Available communications resources and techniques are investigated and analyzed to determine applicability to specific communication requirements.

- Service quality and reliability/availability versus cost - This is a multi-variant analysis of four factors that result in setting the design.

- Maintainability and personnel skill level versus cost - This function evaluates the level of maintainability to be specified in equipment operation and the requisite skills of maintenance personnel available or to be hired against the

cost of maintainability design and personnel skill required to support the operation of the system.

- Growth - The system to be purchased is analyzed for expansion capability. Decisions regarding built-in expansion versus later expansion are assessed in terms of feasibility and cost.

- Transmission design and analysis - Optimizes system parameters and performance against capability and cost.

2. Development of Engineering Requirements

The fundamental question posed is, "What is required"? This is the problem definition stage, requiring a clear understanding of the form of "intelligence" to be moved (i.e., voice, telegraph, facsimile, data, etc.) and a statement of the overall "communication objectives" in terms of the characteristics of the "source" of this intelligence and what the end user intends to make of the intelligence. If certain factors cannot be adequately defined, the known requirements can be carried through the evaluation process while allowing a range of values to be applied to the unknown factors. This will complicate the evaluation and may, in some cases, make them inconclusive; however, a range of solutions or a qualified solution may be useful to the user by assisting him in defining the final communication requirement.

The next question to be asked is "how much" communication is required. This step requires the accumulation of channel requirements over the applicable time period and predicitions of future requirements by extrapolating past growth or other influential factors. In this event, the present system design or expansion of an existing system must start with the known present traffic volume and correlate the expected volume growth during the desired period.

At this point, the "objectives" have been defined and the "quantity" of communications determined, which permits an examination of the more detailed question of the quality of service offered. This stage of the process involves setting down the original objectives with the known volume requirements in terms of the expected or desirable technical performance. It is also possible at this stage to establish the operating requirements for the system and to establish the desired service schedule

as well as the system routing. Consideration of each of these parameters will give rise to ideal values or most desirable objectives which are carried forth into the first survey of available facilities, services, and transmission lines. If the facilities are inadequate, then the original ideal parameters must be compromised in a fashion which will match the available facilities without sacrificing the original objectives. This process may involve several compromises and deviations from the original objectives but all justified by avoiding the time and cost of constructing new facilities.

When the question of facilities has been decided, the original parameters or compromised parameters, as the case may be, are carried into the next stage, that of surveying the "state of the art" techniques of transmission, reception, and signal processing to determine if existing techniques are adequate. If the techniques are not adequate or the equipment is not available, consideration must be given to the time and cost of research and development of new techniques and equipment. Again, if this is not justified, the basic parameters may have to be compromised still further in order to remain within the time allotted to provide the service or the budget allocated to the project. Finally, when the techniques have been decided and the equipment has been selected, all factors are examined in a final "communication system evaluation." In this final evaluation, all factors are examined again by comparing the quantitative and qualitative aspects to the initial capital cost requirements and the costs of maintaining satisfactory service. The factor of obsolescence is examined to determine in the last analysis what additional capital, time, and manpower can be justified to add a given degree of flexibility and accommodations for growth and new service requirements. With these factors satisfactorily evaluated, the "communication system design specification" can be completed and the "communication objective" reached.

3. Channelization and Routing

The term "channel" as applied to PLC and ISW communications systems denotes that portion of the communications bandwidth required for transmission in a single voice signal between two or more stations. The channel may also be used to accommodate, relay, data, telemetry, blocking, transfer-trip, supervisory control, and data acquisition signals. In addition, the channel may be used for multiple services such as voice and data or other combinations. Since the total number of channels has a direct bearing

on the equipment requirements and configuration, care must be exercised in determining the channel requirements.

A traffic plan for the systems should be prepared. This plan will outline the operational requirements of the system and shows the proposed routing of all signals. To determine the number of channels required to accomplish the desired distribution of traffic, the requirements of each type of signal must be determined, and one or more channels allocated to each function. If the equipment types are known, the bandwidth for each type of signal may be determined from manufacturers' data. Where no specific technical information is available, estimates should be based upon the technical characteristics of the equipment employed in similar applications.

Routing of signals is merely the conveyance between users of the information required to carry on the operations of the system. The application of switching to the power system may complicate routing of voice signal somewhat. Review of REA Bulletin 66-8 will provide sufficient detail to understand the trunking of switched systems. There is considerable debate among both users and designers regarding the application of signals other than voice to telephone type switches. Until this is resolved, it is not recommended to use switched facilities for relaying, telemetering, supervisory control, data acquisition, blocking, transfer trip, or other signals critical to the operation of the power system.

4. <u>Frequency Planning and Allocation</u>

One of the most important tasks the design engineer must perform is the assignment of frequencies to new channels. The following are some rules developed from both engineering principle and practice:

- Assign the lower frequencies to long-haul communications and telemetering channels

- Assign the higher frequencies to short-haul circuits

- Extend protective relaying over one line section using higher frequencies.

The following is a synopsis of the steps involved in frequency planning:

- Lay out existing services and frequencies
- Define new and future service requirements
- Select a system-wide frequency allocation plan
- "Shift" frequency plan to accommodate existing frequencies
- "Fit" single-function carrier into 4 kHz slots
- Use lowest frequency on longest line
- Re-use frequencies
- Add new carriers per frequency plan
- Move/up-date:
    - Channel equipment
    - Coupling, tuning and line separation
    - Line traps
- Performance analysis - determine:
    - Signal-to-noise ratio that can be tolerated
    - The relative strength of desired signal
    - The relative strength of interfering signals
    - The amount of permissable outage time.

Consider how a single sideband system may be included into an already crowded frequency spectrum. The first step in this direction is to apply new frequencies only on the basis of a given allocation plan. This plan should have the basic characteristics of being established in 4 kHz slots throughout the spectrum expected to be used. These 4 kHz slots should be arranged on the basis of a standard frequency allocation plan having each of the band edge frequencies divisible by the integer four. This plan should also be selected without regard to existing frequencies in the system.

In other words, for the purpose of establishing the frequency allocation plan, the system should be viewed as a fresh start and plan to utilize the best frequency allocation schemes that our present technology will allow. After the plan has been selected, any new applications of equipment should be made according to the desired frequency plan. This may require moving existing equipment and perhaps some retirement of conventional equipment as required to make room for the applications. This procedure will limit the magnitude of change to existing equipment as the new plan is instituted, and it will allow work toward a completion date in the future when all the individual power line communications systems adhere to the frequency plan.

A suggested plan is shown in Figure II -10. It will be noticed that at any of the seven terminals shown (A through G), the plan does not require anything more stringent than adjacent receiver channels or adjacent transmitter channels on opposite sides of the bus. This arrangement, however, does cause a rather wide spacing (two allocation slots) between the transmitters and receivers on any given line section. This rather wide spacing on any given line section will require a careful choice of wideband trapping and tuning that will allow the desired bandwidth to be coupled to the transmission line. Another interesting requirement of this plan is that frequencies are repeated after every third line section.

It is possible to institute a frequency plan having fewer stringent requirements on the coupling and trapping circuits because it uses only one allocation slot between transmit and receive directions in any one line section. This plan is shown in Figure II -11. An inspection of the conditions at terminal B, however, shows that in one instance a transmitter is transmitting toward Station C in the slot adjacent to a receiver receiving from Section A. This situation leads to some application difficulty because a high attenuation across the bus will be required at this location in order to prevent interference between these two channels. Also, additional isolation will be necessary in order to separate the closely spaced transmitters in some line sections.

A compromise between the wider bandwidth of the system shown in Figure II -11 as compared to that shown in Figure II -10 is illustrated in Figure II -12 . Here the problem area of interference between adjacent transmitter and receiver slots on either side of a bus is

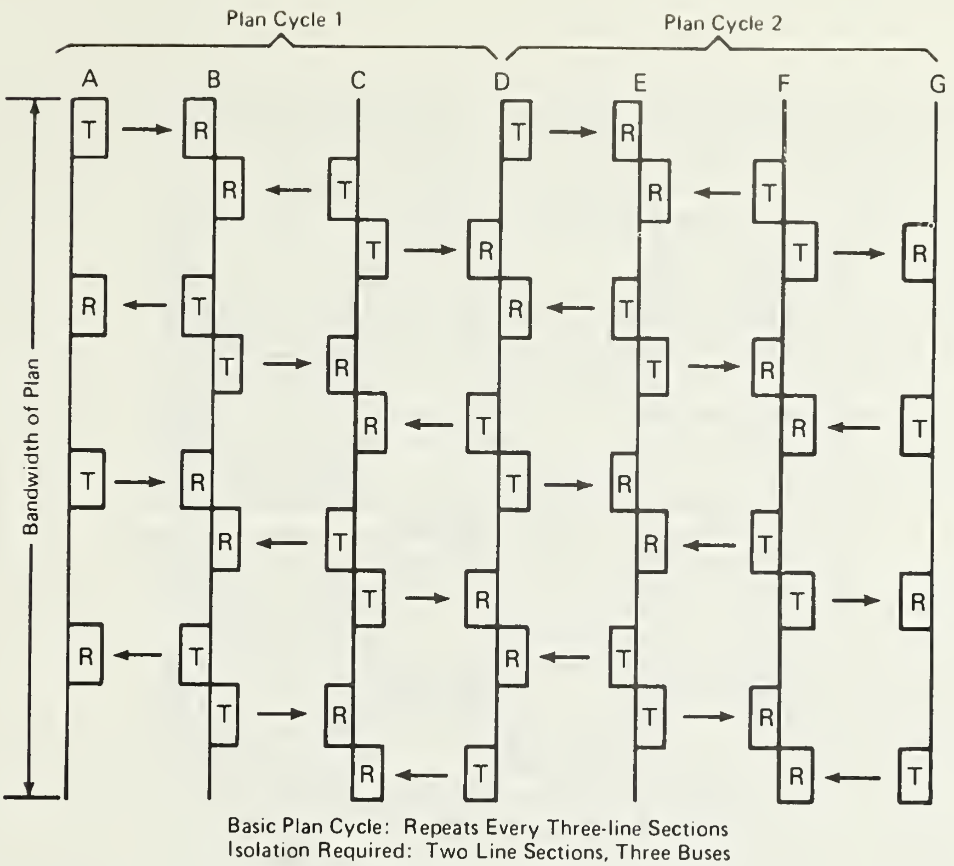


Figure II - 10 Frequency Plan No. 1 For One, or Two, or Four Channel SSB Equipment

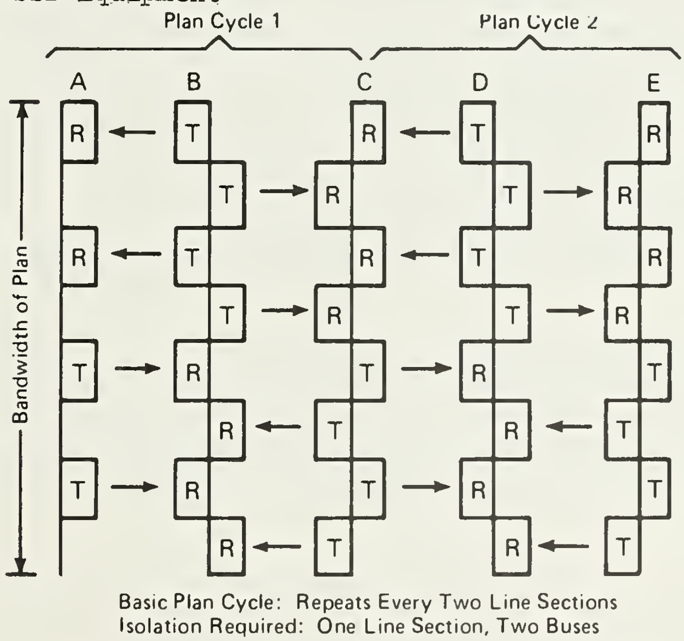


Figure II - 11 Frequency Plan No. 2 For One, Two, or Four Channel SSB Equipment

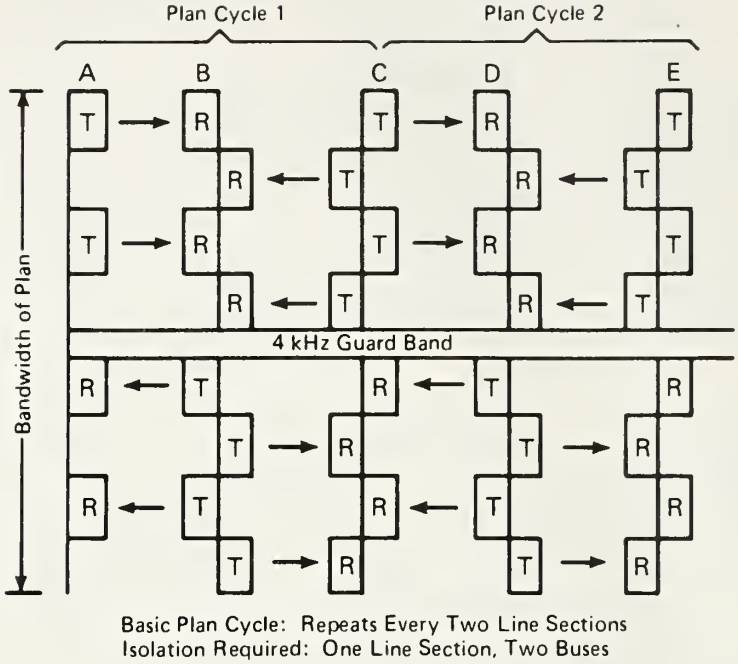


Figure II - 12 Frequency Plan No. 3 For One, Two, or Four Channel SSB Equipment

relieved by providing a guardband of 4 kHz (8 kHz at higher frequencies). The total bandwidth used in any line section is increased by only 4 kHz and the filtering requirement of the adjacent transmitter and receiver on opposite sides of the bus is greatly reduced or alleviated. It may also be observed that in Figures II - 11 and II - 12 the basic frequency repeat pattern is two line sections as compared to three in Figure II - 10. On a systems application basis the use of a frequency plan that repeats after every second line section is of a distinct advantage over one that repeats after every third line section. This plan, however, still faces the problem of close spacing between transmitters in a given line section.

A summary of the main features of the three allocation plans of Figures II - 10, II -11 and II -12 is presented in Table II - 5. It should be noted that the plan in Figure II - 10 requires the greatest bandwidth and that it is the easiest system to apply. Under the Systems Factors heading, it is shown that it provides the best margin against crosstalk and the greatest separation between transmitters in any one line section. Its disadvantage of requiring wider bandwidth is added to by the system problem of requiring a three line section repeat pattern.

The plan of Figure II - 11 overcomes the two disadvantages of the plan in Figure II -10. However, the narrow bandwidth and two line section repeat pattern is achieved by significantly increasing the application problems. The problem created by the combination of adjacent transmitter and receiver slots across the bus is added to by the close spacing of transmitters in the same line sections. Some situations will occur that require capacity loading of the station busses and special filtering in the terminal equipment.

Some of these application problems are alleviated by placing a guardband in the middle of the repeating pattern as shown in Figure II - 12. Full utilization of the plan will be limited at some frequencies by transmitter spacing in a given line section.

Table II - 5
Single Sideband Frequency Plans
Summary and Comparison

Bandwidth required in kHz				System Factors		
	2 ch.	4 ch.	8 ch.	Bus Isolation	Ease of Coupling	Repeat Pattern*
Figure II-10	48	96	192	Note C	Note E	2 Line Sections and 3 busses
Figure II-11	32	64	128	Note A	Note D	1 Line Section and 2 busses
Figure II-12	36	68	132	Note B	Note D	1 Line Section and 2 busses

Note A - Requires good bus isolation: 50 dB may be required to repeat frequencies after three busses and two line sections.

Note B - Eliminates need for difficult transmitter-receiver isolation.

Note C - Provides more margin against crosstalk by repeating frequencies after three busses and two line sections.

Note D - Depending on frequency, isolation of transmitters in coupling equipment may be difficult.

Note E - Easier transmitter separation in coupling equipment to line.

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* At same line voltage.

5. System Expansion

In power systems the need for additional communications usually accompany an expansion of power facilities. The type of overall communication system and the degree to which power line carrier is to be used are determined by the user requirements and the capacity of the system for expansion. The following items must be established

for any expansion project: (1) What new services are required, and what improvements or expansions to existing facilities are necessary? (2) Which of the new services are to be provided by power-line carrier? (3) How can the new carrier services best be coordinated with one another and integrated into the existing carrier system?

Assuming that the first two items are determined satisfactorily in preliminary system design, the third may be expanded, beginning with telephone services. There are several types of power-line carrier telephone equipment with a variety of options available. The application engineer must consider what he wishes to accomplish from a system standpoint, i.e., whether a carrier channel is required as a trunking circuit in a switching network, stricly as a point-to-point circuit, or as a multiparty circuit. Items for determination include method of signaling - dial, ring-down, or common battery - and whether two-wire or four-wire voice operation is required. The same determinations must be made regarding other services to be provided.

Determination of the most practical method for providing other required services, i.e., protective relaying, telemetering, supervisory control, or other telegraphic functions, might begin by consideration of the terminal locations. If several services are required between the same end stations, a choice must be made between combinations of audio tones on a common facility or the use of individual facilities directly in the carrier-frequency range. Economic factors enter into this choice. Two or three services might be provided as individual facilities, whereas a tone combination may be less expensive if several services are to be provided. A limited number of services suitable for audio tone transmission may share a portion of a telephone voice band provided the carrier circuit is of the duplex type.

Other factors to be considered in choosing the best method for a given application include the relative importance of each service and the availability of unused space in the carrier frequency spectrum, increased power requirement, facility space and potential interference.

Carrier equipment of sufficient variety is available today to enable the user to select a type well suited for practically any required service. Published manufacturers' specifications, covering each individual type, provide information concerning its capabilities, including

transmitter power output, receiver sensitivity and selectivity, threshold noise level, maximum distortion, and other pertinent technical data. On the basis of this information, a carrier system can be designed to provide almost any desired degree of reliability and quality. However, any carrier terminal equipment will provide satisfactory service only when used within the limits of its capability. Therefore, the realization of optimum reliability and quality requires a transmission path which is fully adequate under all switching conditions of the power system and all weather conditions. The transmission path is the responsibility of the user.

The key to any successful expansion plan is a properly developed frequency plan. If none exists, one should be prepared and expansion should be predicted upon the dictates of the newly developed frequency plan.

6. System Alternatives

There are several mechanisms for system improvement depending upon what the desired objectives are.

For instance, if lower line attenuation and/or reliability is paramount, the method of coupling may be upgraded -- assuming, of course, this is possible.

Another possibility is the use of inter-circuit coupling. This provides, at worst, a phase-to ground circuit if loss of one phase conductor occurs, or if a line section has to be removed for maintenance.

If an increase in signal-to-noise is required, increased transmitter power output may be a solution, or even investigating means for reducing circuit losses.

If transformers at substations prove detrimental to system operation, the use of by-pass circuits may be called for.

The use of exalted transmission should be considered for priority functions.

Specialized telephone switching developed for PLC applications may extend both the use and performance of telephone service.

Equipment allowing the conversion of a multifunction system automatically to a single function relay set is particularly useful when relay sets on opposite sides of the

bus are on the same baseband frequency.

Alternate path routing is an extremely useful technique that provides redundancy in case either a loss of power line continuity or equipment failure occurs.

Use of either baseband or audio repeaters should be considered where it is not necessary to use certain signals at a particular station. In this instance the signal is routed electrically around the station.

Automatic squelch is available which disables the receiver during high noise periods, thus avoiding the repeating of noise through intermediate stations.

The engineer should investigate various possible alternatives to enhancing performance or eliminating system problems.

E. PLC and ISW Equipment Facilities:

All carrier facility systems are comprised of carrier frequency generation, transmission, coupling, trapping, and tuning equipment. In conjunction with these units are the actual physical facilities that both support and house the power system communications equipment. Figure II - 13 is a basic system drawing showing the major components to be covered in this section. Note that the user components: protective relays, telephone, telemetering are not covered in this bulletin, but form a part of another bulletin to be issued as part of this series.

1. Carrier Frequency Transmission Equipment

a. Single Function - AM

AM equipment date back to the first twenty years of power line carrier and are only noted herein for some historical interest and usage in conjunction with AM tone and pilot relay functions. As a result of its additional bandwidth and susceptibility to noise interference, AM is used in the most limited manner in current day PLC systems. The broader receiver passband, the more energy that will be passed, and hence the more deleterious the effects of noise and interference are. The amplitude modulation used in PLC is essentially that used in standard commercial broadcast systems. It is extremely vulnerable to atmospheric and Corona noise. Because of its limited use, single function AM will not be further dealt with in this bulletin.

b. Frequency Shift Keying (FSK)

Frequency shift carrier modulation is used for such services as teletype, telemetering, data, load control, and frequency control, plus transfer-trip relaying.

Frequency shift keying is a method by which a continuous carrier is transmitted with the capability of being shifted to another frequency in order to initiate some function or indication. Two types of FS carrier equipment are generally used: two-frequency and three-frequency. Since there is always a carrier on the system with FS modulation, a failure of the carrier equipment or communication circuit is readily detected and contributes to high system reliability. Also, FS equipment is more immune to noise and interference, providing a greater security against false operation. Its lower distortion feature is very important in usage in

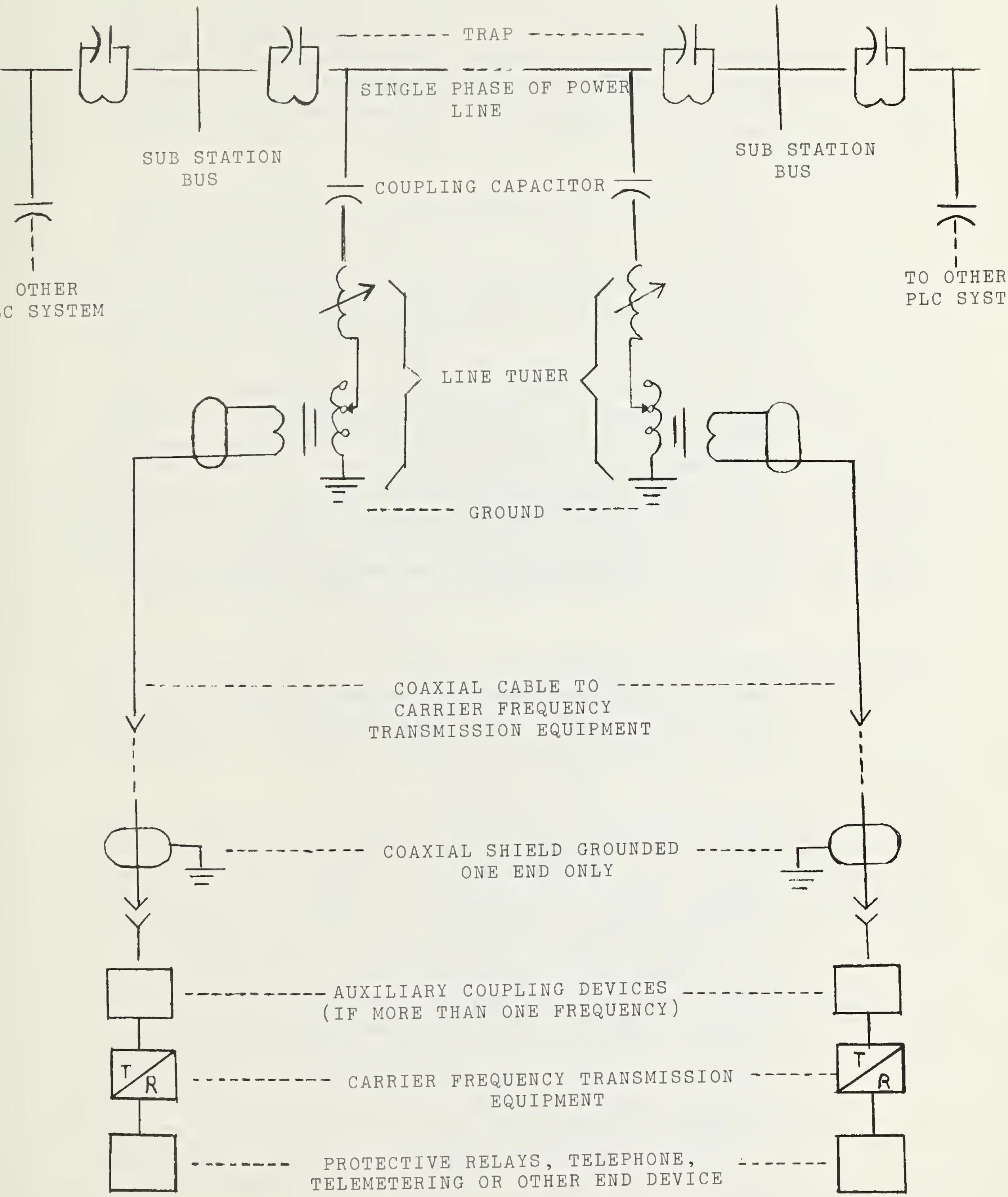


Figure II - 13 SINGLE FREQUENCY LINE TO GROUND COUPLED PLC SYSTEM

teletypewriter and telemetering service.

Another important feature of FS transmission is its ability to operate over much higher attenuation (i. e., with a much lower signal-to-noise ratio) than conventional on-off continuous wave transmission. This is mainly due to the use of a limiter and a balanced discriminator, which tend to cancel the effect of noise voltages.

With two-frequency FS equipment, the lower frequency carrier is transmitted continuously during idle conditions (no function or indication to be initiated), and is shifted to the upper frequency to initiate some action. Two-frequency FS modulation is adaptable for such services as teletype, telemetering and data communications.

With three-frequency FS equipment, the "center" frequency is the one transmitted continuously in the idle condition. This type equipment is capable of performing a double function, in contrast to the single-function capability of two-frequency FS equipment. Three-frequency FS equipment may be shifted to its upper frequency for one function and to its lower frequency for a second function. This type of FS equipment is adaptable for such services as supervisory control and frequency control.

One of the applications of FSK is in protecting transformers with no high voltage breaker (to the line side). The tripping signal for the transformer fault is sent over the power line to a remote breaker. The receiver output relay directly trips the breaker.

Also, a frequency-shift (FSK) signal may be used where security against incorrect operation is required. In this case, a carrier signal is transmitted continuously at a guard space frequency. Reception of the guard frequency saturates the receiver, making it insensitive to noise voltages in the power line. To transmit a trip signal, the transmitter frequency is shifted producing a receiver discriminator output of opposite polarity and trips the circuit breaker at the receiving terminal. Simultaneously the transmitter power may by increased to ensure that the trip signal is of sufficient magnitude to be detected by the receiver. A characteristic of FSK units used for the above application is that the receiver passband need only be wide enough to include the guard frequencies and a small safety margin.

Figures 14a, 14b are block diagrams of a FSK transmitter and receiver. In this instance, the transmitter is crystal-controlled. The keying circuit may accommodate channel frequencies from about 30 to 300kHz. Power output ranges from 1 to 10 watts. Typical usage of an FSK unit of this type employs two signals (or frequencies), a guard signal, and a trip signal. The guard signal is at the normal standby frequency and trip signal is obtained by shifting an oscillator frequency by some fixed amount. This may vary from 75 to 200Hz. This shift is produced when the relay system produces a tripping signal as shown in Figure II - 15.

The incoming carrier signal enters the receiver and subsequent to filtering is passed to the mixer where it is combined with the output frequency from dual oscillators to provide an intermediate frequency (IF) in conjunction with the incoming frequency shifting from guard position to trip position. The IF signal is then limited and thereafter detected by a discriminator circuit. For transfer-trip use, the receiver discriminator frequency is shifted a small amount in the trip direction producing a larger segment of the crystal filter pass-band on the guard side of the discriminator and a smaller amount on the trip side. The result is to negate the effects or possibility of a high noise level on the transmission line producing a spurious trip output from the breaker.

The preceding usage suggests the use of receiver logic. The following is typical of the logic employed for transfer-trip relaying.

- A guard signal must be received before a trip signal
- The receive signal must shift from guard to trip with no intentional delay
- The trip signal must be received long enough to time out an adjustable delay
- There should be no sustained high noise level on the channel

Altering the receiver logic and filtering allows for different types of services to be provided by FSK such as:

- Transformer Trip Protection
    - Transformer differential
    - Breaker failure
    - Overvoltage

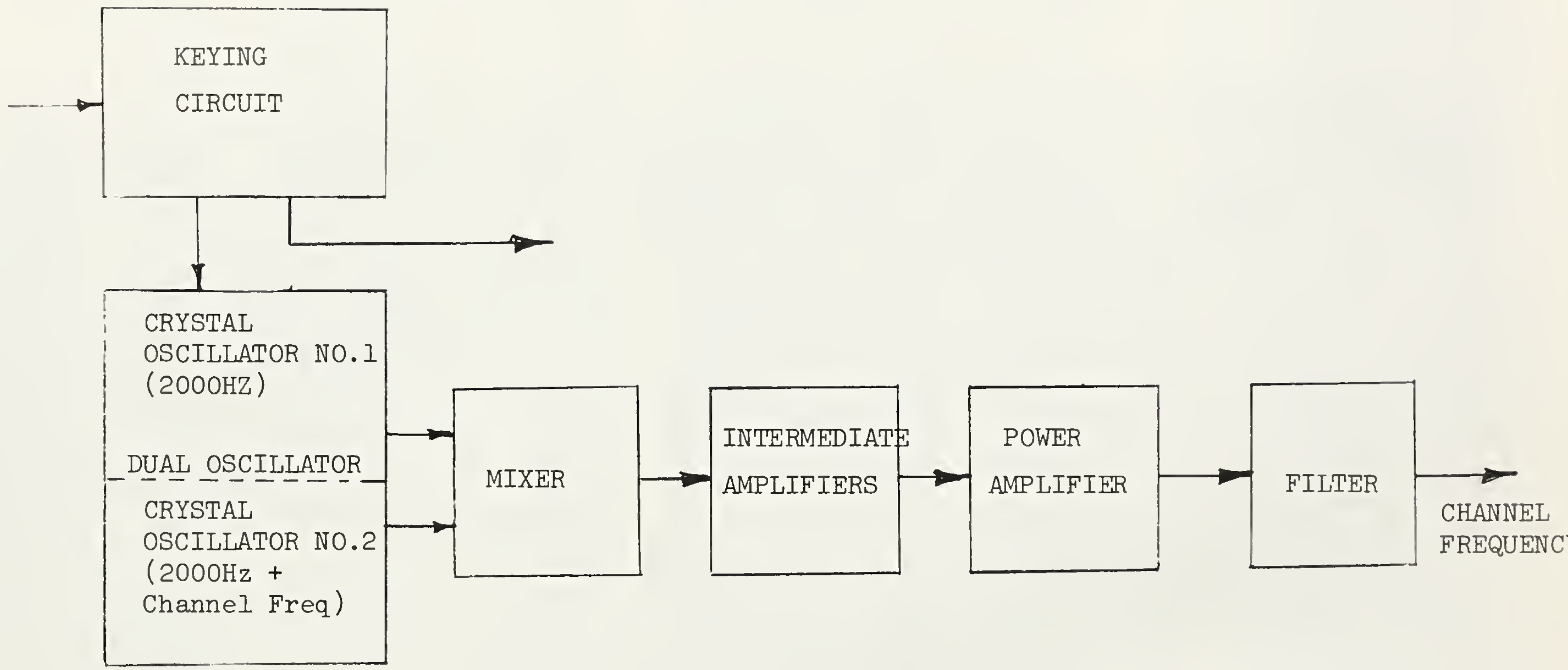


Figure II - 14a Simplified Block Diagram of FSK Transmitter

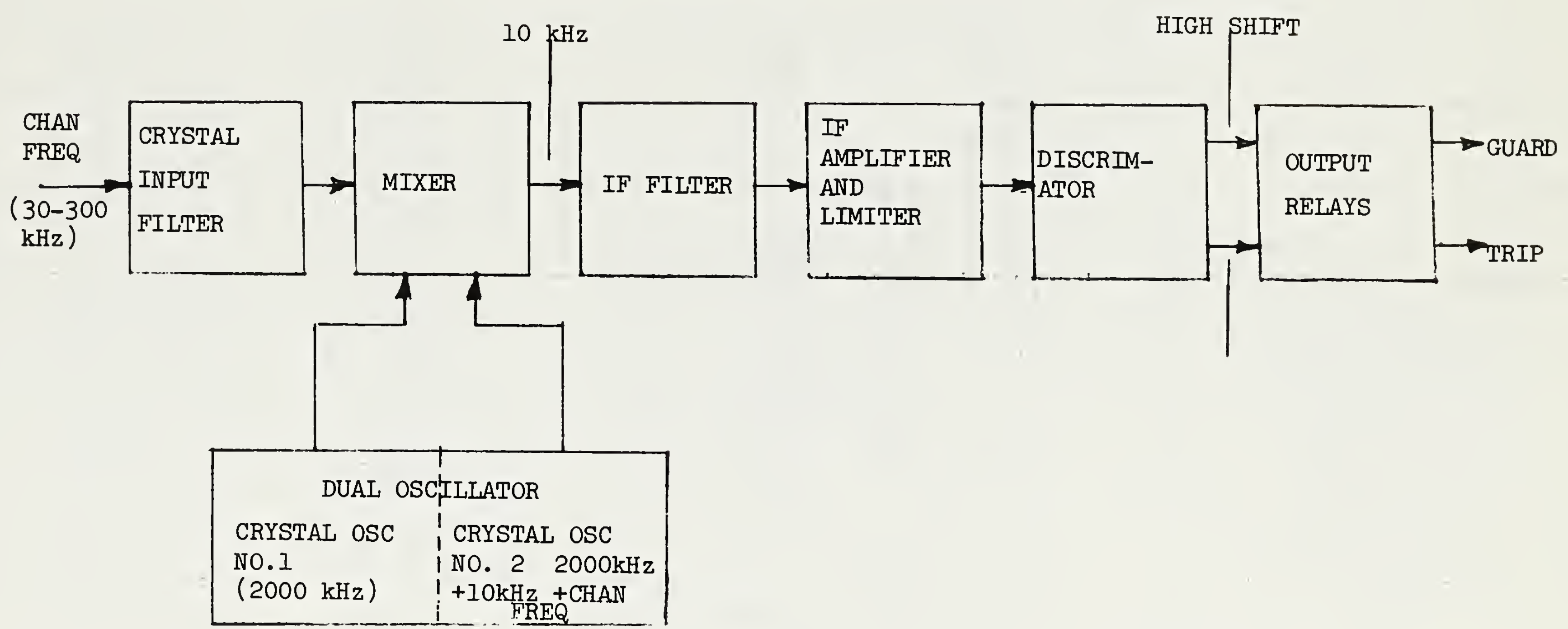


Figure II - 14b Simplified Block Diagram of FSK Receiver

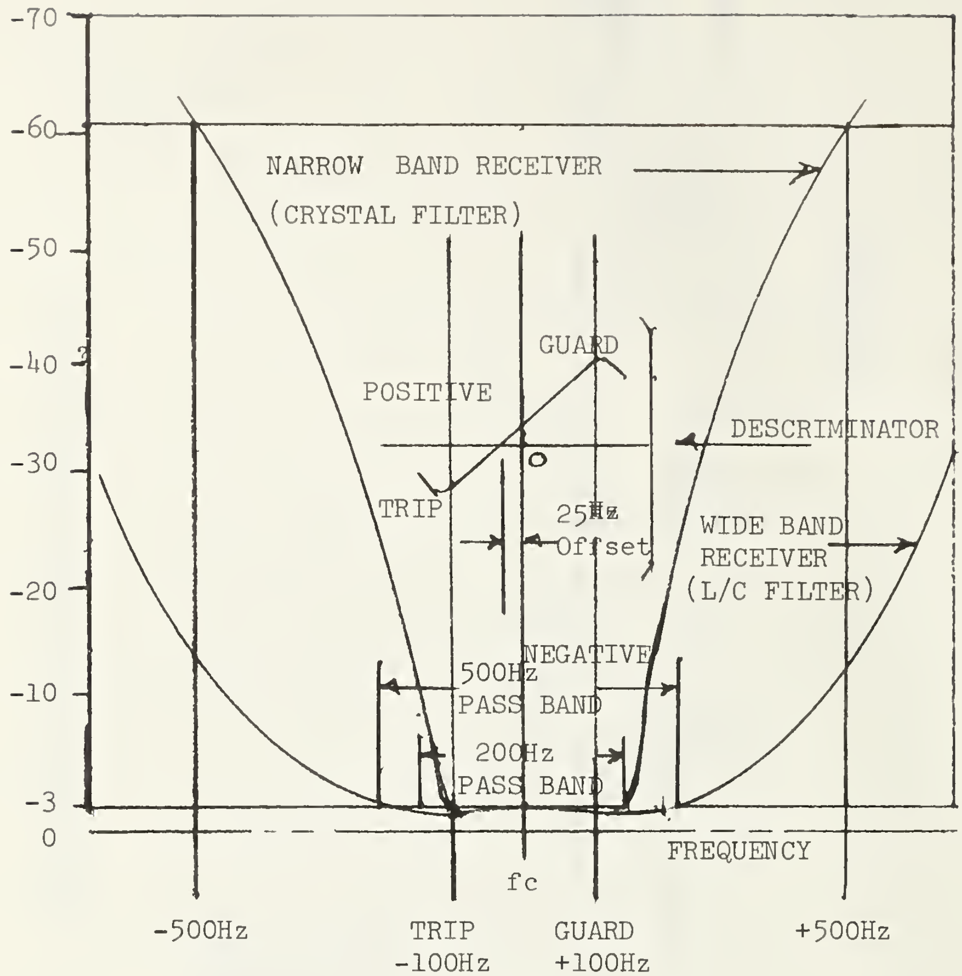


Figure II - 15 Typical Filter and Discriminator Curves of Narrow and Wide Band Frequency Shift Carrier Receivers

- Line Protection
  - Permissive overreach
  - Direct under-reach
  - Permissive under-reach
  - Unblocking
  - Phase comparison
- Teletype Service
- Load Management
- Load Control
- Supervisory Control

The above is only a partial listing of what types of services can be provided using FSK.

c. <u>Single Sideband (SSB)</u>

Single Sideband transmission is amplitude modulation with one sideband removed. Additionally, the carrier may be suppressed at the transmitter and reinserted at the receiver to reduce the unnecessary power transmitted since one sideband contains the same intelligence as the modulating signal on two sidebands. This allows the entire transmitter output power to be used for one intelligence bearing sideband. The SSB frequency requirement is one half that required for amplitude modulation and one half or less, than that in the case of FM. SSB has a two-fold advantage of both conserving the frequency spectrum and a significant improvement in signal-to-noise ratio over an incoherently detected AM system. A further advantage is that a suppressed carrier SSB system is reduced in susceptibility to Corona modulation which occurs in direct proportion to the signal strength received.

With transmitters of equal power capability, each 100 percent modulated single-sideband equipment usually provides a signal-to-noise advantage of 6dB or more over AM equipment. The advantage is dependent on the nature of the noise and how effective the noise level within the 6kHz bandwidth required for the AM signal compares with that in the 3kHz bandwidth required for the single-sideband signal.

A single sideband receiver does not require the presence of a continuous carrier in the received signal. For this reason it is possible for a single-sideband receiver to receive intelligible signals from more than one source simultaneously by reinserting one carrier to demodulate all signals. Single-sideband equipment is available which makes use of this principle to

provide party-line operation of duplex equipment. A repeater is used at intermediate points which transmits the same band of frequencies in each direction, and likewise receives the same from each direction. signals are partially demodulated and translated in frequency before being amplified and retransmitted. This technique of exchanging and re-using the same frequencies is called frequency frogging. Although equipment requirements for a breakout repeater of this type are only slightly less than with cascaded individual channels, additional frequencies are not required.

Most SSB equipment offered today feature a building block or modular concept, and is of solid state design. It is not sufficient to merely view the transmitter and receiver functions, rather, it is necessary to consider all of the elements which constitute a SSB terminal. Figure II - 16 is a block diagram of a typical SSB terminal.

The voice channeling equipment provides the basic modulation steps in the SSB system. It also provides the necessary termination for interfacing the SSB equipment with the associated telephone, tone equipment or other end devices.

The signaling adapter provides the interface connections between the associated telephone system and the SSB channel equipment so that the module can match the speech and signaling terminations used by different telephone systems. Typical terminations provided are: E&M signaling, two and four-wire central battery ringdown, subscriber dial telephone end, subscriber dial exchange end and bypass adapter for data channels.

The audio hybrid converts the basic four-wire channel to a two-wire circuit using a transformer hybrid. Secondary surge protection is provided at the two-wire input. In four-wire applications, a bypass module is used to provide signal continuity.

The signal-to-noise ratio can be improved by using the compandor to compress the dynamic range of the voice signal at the send end and expand it at the receive end. Thus, a much higher level of voice intelligibility is obtained under poor line-noise conditions.

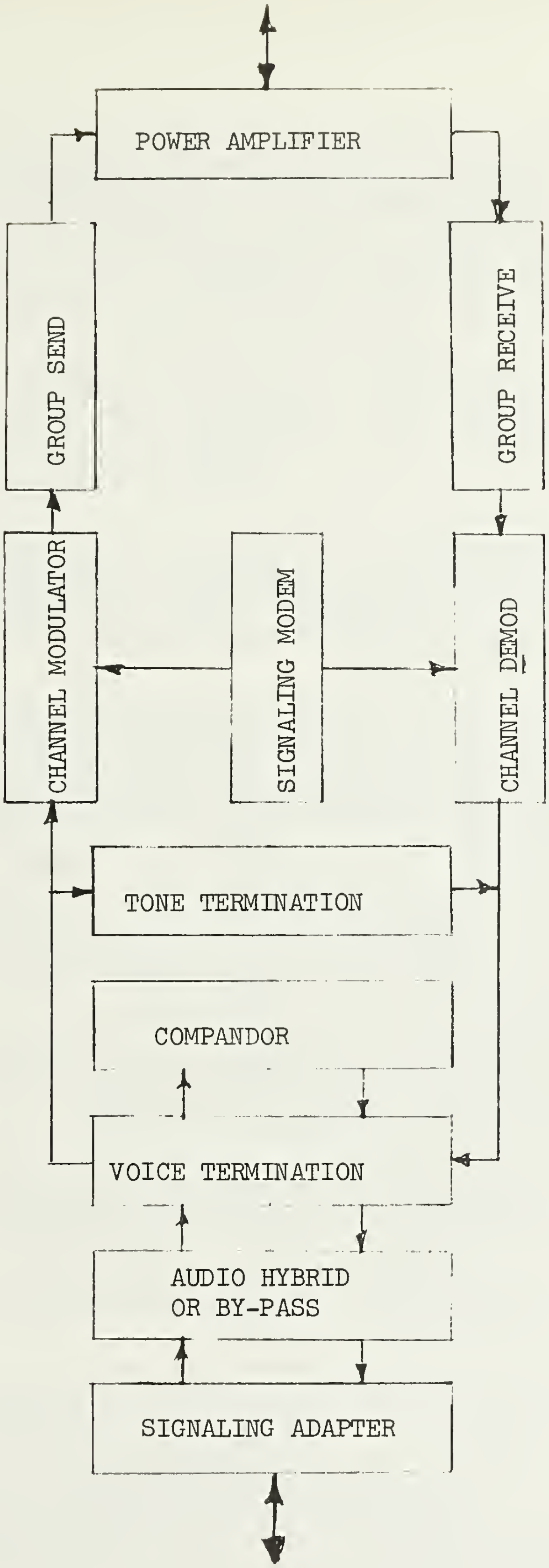


Figure II - 16 Block Diagram of Typical SSB Terminal

The voice termination unit provides balanced, four-wire send and receive terminations, plus a voice limiter and signal level adjustments. The voice limiter circuit in the send path limits the voice peaks to prevent over-modulation. Also included in the send circuit is a transistor switch (voice block) which, in some applications, is used to cut off the voice and allow full channel power to be applied to either tones or baseband frequencies. A typical application of this voice block circuit is in protective relaying where full power for the relaying functions greatly increases reliability.

The channel modulator provides the modulation to translate the audio frequencies to baseband frequencies; to line frequencies in direct-to-line modulation, and it also selects either the upper or lower sideband to be transmitted.

The channel demodulator provides the modulation to translate the baseband frequencies or the line freqencies, to audio frequencies. The signaling tone signal is extracted and connected to the signaling modem module.

The signaling unit provides the modulation to convert the input pulses to an AM audio tone (3600Hz or 3825Hz) for transmission and the demodulation to convert the AM audio tone to output pulses.

In telephone dial (E&M) and subscriber applications, the pulse-correcting unit provides circuitry to reshape and correct the make-break rates.

In PLC,telemetering and control functions are often transmitted via frequency-shift, amplitude-modulated, or keyed audio tones. Tone transmitters and receivers are available with various bandwidths for spacings of 100 to 510Hz, depending upon the functions to be transmitted.

The audio bandwidth available over power-line carrier telephone circuits is usually in the order of 300 to 3,000Hz. With sufficiently high-quality circuits, speech with good intelligibility can be transmitted over a bandwidth of approximately 300 to 2,000Hz. The remainder of the audio bandwidth available in a duplex carrier circuit may be utilized for the continuous transmission of audio tones.

A tone termination unit is used in conjunction with a speech-plus, or for tones only audio channels. The module has provision for three independent ports by which audio tones can enter into the system. The receive port operates in conjunction with a high-pass filter (speech-plus application), which blocks all voice signals making tone repeating more desirable.

The basic transmission equipment includes the carrier generation system, power supply, power amplifier and other common equipment. This equipment operates in the following manner.

The function of the group transmit unit is to convert the baseband frequencies to line frequencies. This conversion or modulation step is omitted in low-frequency (8 to 48kHz) equipment in which line frequencies are directly obtained from the channel units.

The second function is to reinsert the pilot carrier frequency which was suppressed so that the pilot can be sent to the remote receiver for AGC and frequency-lock purposes. The output is amplified by the power amplifier in accordance with specified output level. A surge type of output filter is included to protect against transients originating from the power line.

A hybrid unit is used to send and receive frequencies.

A group receive unit provides the demodulation step which translates the line frequencies to baseband frequencies. This demodulation step is omitted in low frequency (8 to 48kHz) equipment, in which the line frequencies are directly applied and demodulated to audio frequencies. The group receive unit also provides amplification, impedance matching and access to the AGC circuit and other channel functions.

The AGC compensates for variations in signal level caused by line attenuation changes.

The master oscillator and carrier generator modules generate the carriers for insertion into the send and receive signal paths.

2. Carrier Frequency Coupling Equipment

A power line carrier system consists of three distinct parts: the terminal assemblies, consisting of the trans-

mitters, receivers, and associated components, as discussed above, the coupling and tuning equipment, which provides a means of connecting the terminals to selected points of the high-voltage system, and the high-voltage system itself, which must provide a suitable path for transmission of the high-frequency energy between the terminals. At the terminals, one or more transmitters and /or receivers are required, depending on the number of functions to be performed.

Coupling to power line conductors is accomplished by means of high-voltage coupling capacitors which serve to conduct the carrier signals, while blocking 60Hz power from the carrier equipment. For insulated ground wires, where the voltages encountered are lower, either transformers or coupling capacitors may be used.

Intermediate points between terminals may require by-passing of the carrier signals around discontinuities such as switches or transformers. In this case, coupling is made to both sides of the discontinuity, and line tuning equipment tuned to the carrier frequencies is used to complete the carrier path between the two coupling points.

Line traps are inserted in power line conductors to minimize the loss of carrier power into extraneous lines and to direct the signals over the desired line section. By proper choice of carrier frequencies, several services can operate over the same line conductors without interference. Frequently, some of the carrier equipment can be used in common by two or more of the services, thus minimizing the investment.

Terminal equipment is usually the same regardless of line length, except for variations in transmitter output power, which is generally in the range of 1 to 20 watts (with occasional application of other output up to approximately 100 watts).

a. Coupling to the Power Line

The transfer of power line carrier energy may take place several ways so that the carrier signals will propagate down the line. Modal theory shows that carrier signals generally flow in all three phases of a power line, as well as in any static wires present. The coupling depends on the specific coupling arrangement selected.

The coupling methods available are:

- Modal
- Center phase-to-ground
- Center phase-to-outer-phase
- Intercircuit

The first three methods use the three-phase power line; the last method used couples the signals into two separate power lines.

Modal coupling is theoretically the lowest loss method for coupling carrier signals to and from the power lines. It has the advantage of providing a high channel dependability, since it can withstand a single phase or a two-phase fault to ground at the substation without the carrier signal being eliminated. The disadvantage is high cost, since three sets of tuning equipment are required. The arrangement for modal coupling is shown in Figure II - 38 . Two isolation transformers are connected so that the current supplied to the center conductor of the power line is 180° out-of-phase with the currents supplied to the two outer conductors (equal currents) and equal in magnitude to their sum.

The simplest and most frequently used coupling method is the the center-phase-to-ground scheme shown in Figure II - 35 . It utilizes the minimum amount of equipment and is reasonably efficient. Center-phase-to-ground coupling has a theoretical loss compared to modal coupling of 1.8dB at each end of the line. Substantial additional losses can occur, however, if static wires are not used on the power line and the soil in the vicinity of the substation has poor conductivity.

Center-phase-to-outer-phase coupling is illustrated in Figure II - 36 . In this arrangement the currents are equal in magnitude and 180° out-of-phase. It has the advantage of being somewhat more efficient than center-phase-to-ground coupling. It has 1.2dB loss compared to modal coupling instead of the 1.8dB loss at each end of the line for the center-phase-to-ground method. This method provides greater channel dependability than center-phase-to-ground coupling, since a single phase fault at the substation will not eliminate the carrier signal. Further, its coupling loss is not significantly affected if static wires are not used and if the ground conductivity is poor.

Intercircuit coupling is generally a center-phase-to-center-phase coupling between two separate power lines in close proximity to each other. This arramgement provides two separate paths for the carrier signal as shown in Figure II - 37 .

b. Coupling Capacitors

In order for an efficient transfer of energy between transmitter or receiver and the line to take place, a coupling capacitor is required.
The coupling capacitor, along with its associated drain coil and carrier accessories, provides a low impedance path between the carrier equipment and the 60Hz power system, while simultaneously providing the necessary reduction in 60Hz voltage to permit the use of low voltage carrier equipment.

The coupling capacitors' reactive impedance is very high at the power frequency, but nominal at carrier frequencies. This device is connected directly to the transmission line conductor. For phase-to-phase coupling, two capacitors are required. Coupling capacitors are physically composed of several paper-capacitor elements connected in series and immersed in oil. The outer containeris aporcelain cylinder with multiple rain-shed skirts which provide a long creepage path. They are equipped with a circular metal fitting on each end which serves both for physical support or mounting and for electrical connection. A gas bubble is usually left inside the cylinder to allow for thermal expansion of the oil, although some European types use an expanding metal diaphragm so that the inside can be completely oil filled.

Coupling capacitor voltage ratings are the nominal phase-to-phase voltage of the transmission line on which it is to be used, although the actual potential across the capacitor is the phase-to-ground voltage. In addition to continuously withstanding this voltage, the capacitor insulation must withstand high-voltage impulses caused by lightning and switching surges and is sometimes subjected to considerable over-voltages for extended periods of time. The American National Standards Institute publication C93.1 dated 1972 should be consulted for a listing of coupling capacitor characteristics.

The capacitance and voltage rating of every capacitor of a particular manafacturer's type are coordinated so that the units may be stacked to provide direct addition of their voltage ratings.

The capacitance of coupling capacitors is determined somewhat as a compromise between the economics involved in their manufacture and the requirements of carrier applications.

Coupling capacitors are typically made using a paper/liquid dielectric system. Strips of Kraft paper are interleaved with strips of aluminum foil and wound into rolls. These rolls are flattened and stacked in a hollow porcelain insulator with external shed. The rolls are connected in series to provide a large voltage withstand capability. The capacitor unit is then filled with mineral oil (in some cases polybiphenol chloride) and sealed. The combination of the paper and the liquid forms a reliable dielectric system.

The capacitor units are mounted on a metal base housing. The base unit usually contains a power frequency drain coil to limit the buildup of excessive power frequency voltages, protective gaps to limit transient voltages and a grounding switch to eliminate power from the carrier lead during maintainance or repair work.

Single capacitor units are available for line-to-line voltages in the range from 34.5 to 161kV. Where larger ratings are required, combinations of single units are stacked to provide the necessary rating.

Coupling capacitors provide for a phase-to-ground feed of the carrier signal on one phase of a power line. Where the application requires that the signal be fed to more than one phase, additional coupling capacitors are required.

A coupling capacitor is operated with a line tuner to form a bandpass or highpass filter at carrier frequencies.

The bandwidth available for a bandpass tuner/coupling capacitor combination is proportional to the value of the coupling capacitor for a specified geometric mean frequency (GMF). For a given type of coupling capacitor, the value of capicitance is ideally inversely proportional to the line voltage.

In order to provide different capacity values for a specified voltage rating, capacitor rolls with several different cross-sectional areas are used. Table II - 6 lists the approximate range of coupling capacitance available for various voltage classes.

Table II - 6

CAPACITANCE RANGES

Voltage Class kV	Capacitance Range Microfarads
34.5	.004 - .010
46	.004 - .015
69	.003 - .015
92	.002 - .020
115	.0019 - .020
138	.0014 - .016
161	.0012 - .014
230	.0009 - .010
287	.0006 - .007
345	.0005 - .006
500	.0014 - .005
765	.003

c. <u>Potential Device</u>

An additional function may be performed by the coupling capacitor in conjunction with additional circuitry in the base housing. The coupling capacitor is utilized as a power frequency voltage divider with a tap being brought out of the bottom capacitor unit. This tap is connected to a reactor/transformer combination (also protective gaps and other components) which converts the tap voltage to a 115 volt output when rated voltage is applied to the capacitor stack. This unit provides inputs for protective relays and/or metering equipment.

The coupling capacitor used in the above manner is a potential device, and provides the same coupling junction as the coupling capacitor, plus a 60Hz voltage source for operation of such devices as protective relays, synchroscopes, voltmeters, indicating lamps, wattmeters, and similar instruments requiring a potential source of approximately constant voltage ratio and negligible phase shift with respect to the high voltage circuit.

d. Line Tuning Units

The line tuning equipment is connected in series with the high-voltage coupling capacitor to provide for the:

- Efficient coupling of carrier transmitters and receivers to the power line or cable
- Carrier by-passes around power transformers, switches and other discontinuities in the power line at carrier frequencies
- Attenuation of undesired signals
- Protection of personnel and electronic equipment from the high voltage of the power line
- Impedance matching of carrier equipment to the power line or cable

Line tuning equipment may be very simple or fairly complex, depending on the number of carrier signals to be passed through the coupling capacitor. The number of signals that can be coupled through a single coupling capacitor depends on the value of the capacitance, the signal frequencies, the signal bandwidths, and the complexity in the line tuning equipment. The most commonly used line tuning equipment is available in standard units, having various arrangements of variable inductors and capacitors that can be combined to form series and parallel resonant circuits for one or more channels in the carrier frequency range. The types of tuners in use are the single frequency resonant, two-frequency resonant, wideband bandpass, and wideband high-pass

Single frequency resonant tuning involves the coupling of one frequency between a single phase of the power line and ground (single phase-to-ground coupling) using one coupling capacitor. An impedance matching transformer and a line tuning inductor comprise the basic elements of the tuner as shown in Figure II - 17 . A protective gap grounding switch and compensating capacitor (for operation at higher frequencies) are also contained in the tuner. These elements isolate the transmitter and receiver equipment from the 60Hz power line voltage, cancel (by

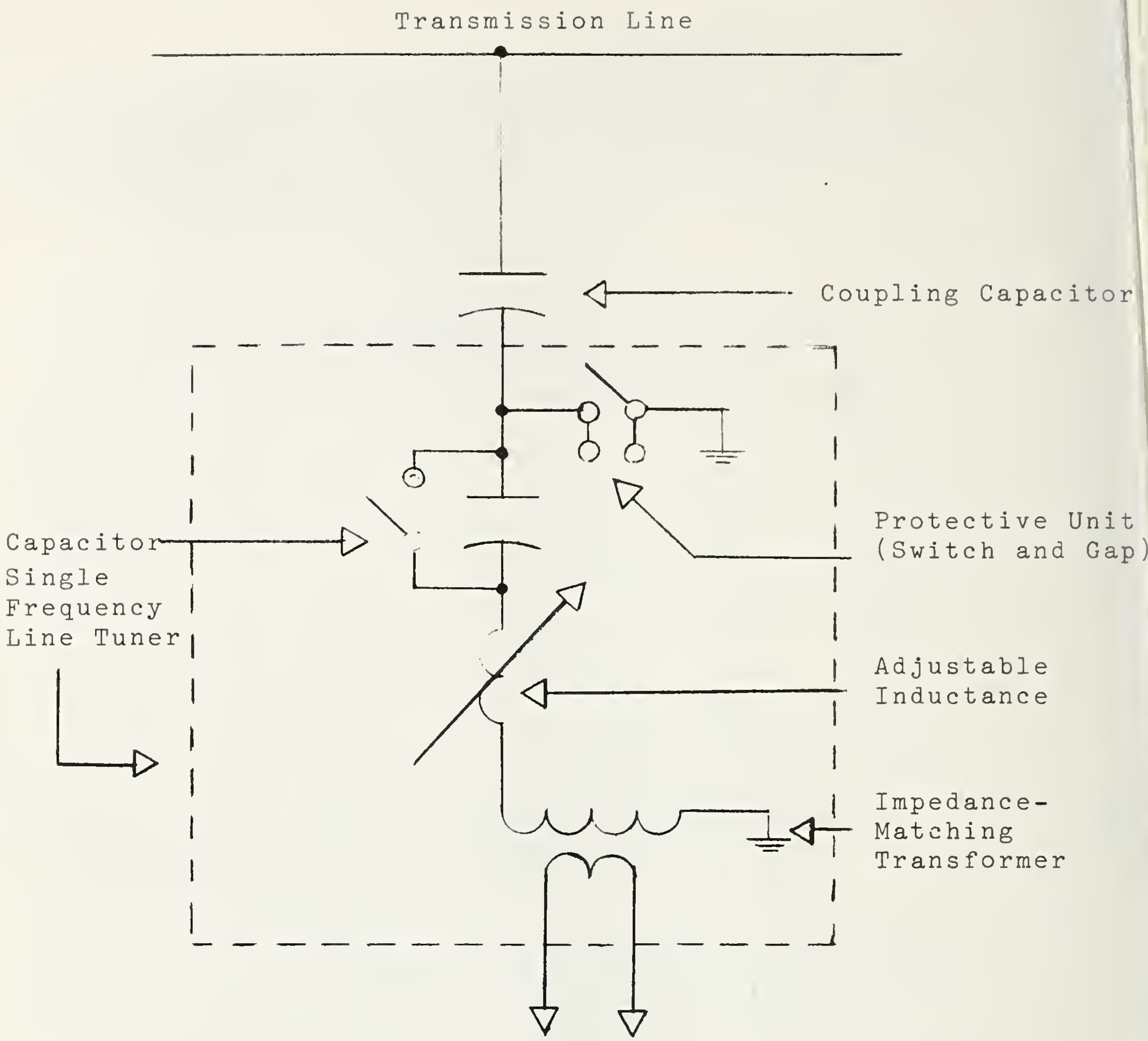


Figure II - 17

Typical Single Frequency Line Tuner

series resonance) the inductive and capacitive reactance combination to obtain an equivalent low resistance path for the carrier signal, and provide matching of the low impedance transmitter/receiver equipment (and the associated coaxial cable) to the high impedance of the overhead transmission line. For power cable circuits, special low ratio impedance matching transformers are used. Higher coupling losses are incurred when coupling to cable circuits because the impedance ratio of coupling components and power cable characteristic impedances are low.

The losses caused by the line tuner/coupling capacitor combination vary with the frequency, the capacitance of the coupling capacitor, the line tuner characteristics and the apparent impedance of the power circuit.

When more than one frequency must be coupled to a line using the same coupling capacitor, either the single frequency tuner will be operated off-resonance for all but one of the frequencies or a broadband tuner will be required. An off-resonance tuner introduces a reactive component (and increased losses) into the transmission path, but in a number of applications, the loss can be tolerated. Provided the total tuner attenuation is not too great, a narrow band frequency shift type channel can operate practically unaffected and it is common practice to run a number of such channels closely spaced through a single frequency tuner.

Two-frequency tuners are used where two signals are to be coupled to the line and the impedance mismatch of a single frequency tuner off-resonance cannot be tolerated. Figure II-18 shows a basic two frequency tuner.

To permit independent tuning, parallel resonant traps are inserted in each path to attenuate all frequencies except the resonant frequency. These elements introduce losses, but for a two-frequency tuner, if the frequencies are separated by 25% or more of the higher frequency, the losses in the trap unit at the resonant frequencies are negligible.

In general, the coupling loss of a two-frequency tuner is twice that of a single frequency tuner (other factors being equal). Conversely, the bandwidth of each path is approximately half that of a single frequency tuner provided the frequency spacing rules are observed.

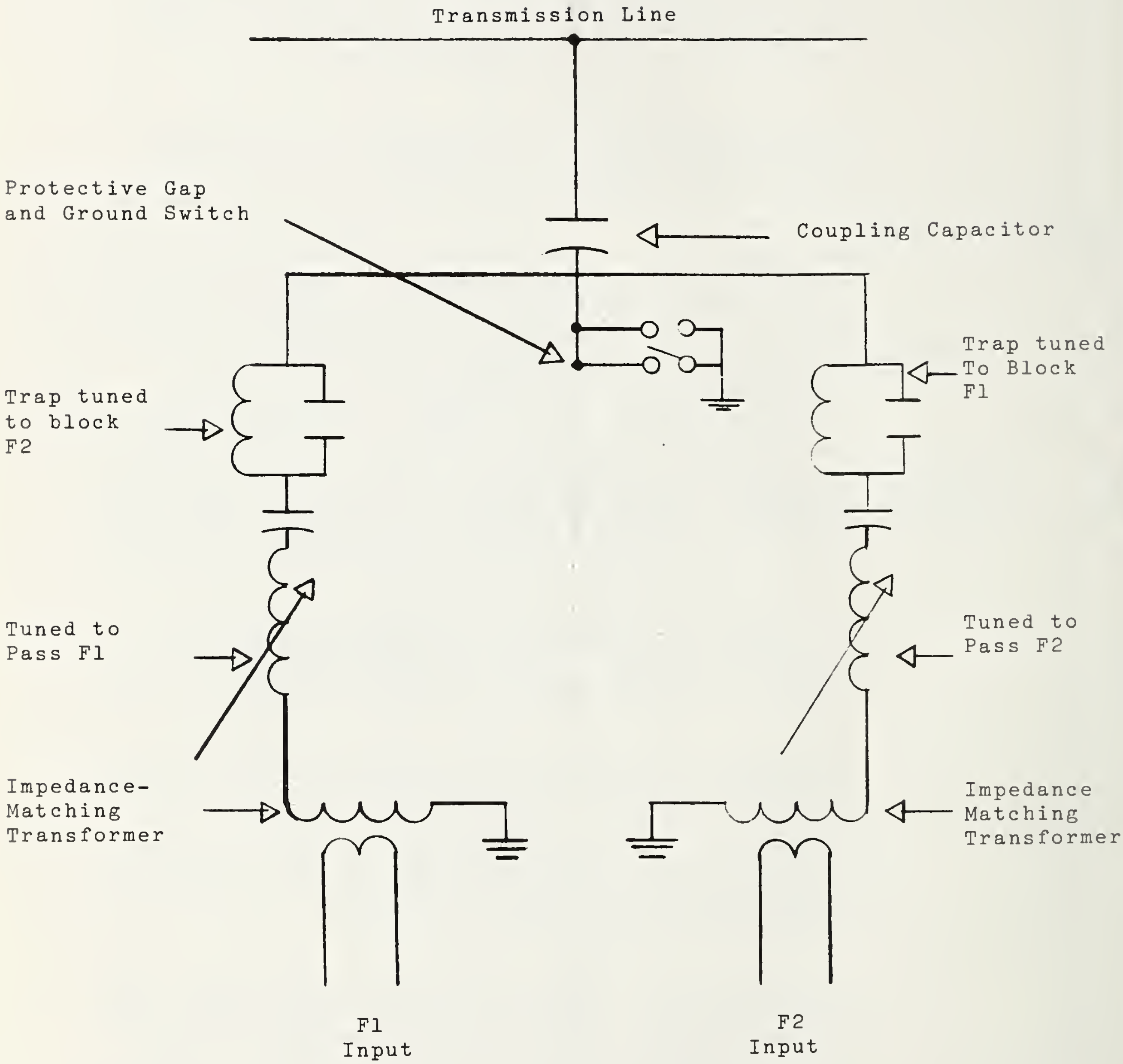


Figure II - 18

Two-Frequency Line Tuner

When using a two-frequency resonant line tuner to couple two or more frequencies onto a line, adequate frequency spacing must be observed. The recommended spacing is 25% of the higher frequency or 25kHz, whichever is greater. Failure to observe the recommended frequency separation can result in interaction between the two frequencies, producing excessive attenuation, and possibly intermodulation.

The problems encountered in the resonant tuners prompted the development of broadband coupling networks using reactance elements to form the bandpass of highpass filter networks (Wideband tuners). Generally, this type of tuner is essential when it is necessary to pass a broadband of frequencies with low loss over the same phase wire. A bandpass tuner, together with its associated coupling capacitor, forms a bandpass filter as illustrated in Figure II - 19.

The bandpass tuner is designed to pass a maximum band of frequencies on both sides of a Geometric Mean Frequency (GMF). The GMF is defined as the square root of the product of the band limit frequencies. The bandwidth is proportional to the coupling capacitance, the load impedance, and the square of the GMF. Obviously increasing the GMF is the most effective means for increasing bandwidth, provided the lowest required frequency stays within the passband.

Bandpass tuners are available in two types, Fixed Wideband and Adjustable Wideband. The fixed wideband tuner provieds a somewhat larger bandwidth than the adjustable wideband tuner at the expense of a somewhat larger non-uniform insertion loss across its passband. The adjustable wideband tuners provide a lower and more uniform insertion loss. As in the case for resonant tuners, an impedance matching transformer, protective gap, and grounding switch are provided for bandpass tuners.

A highpass tuner, together with its associated coupling capacitor, forms a highpass filter as illustrated in Figure II - 20 . This tuner has substantial impedance variation in its passband. This type of tuner is designed to pass a maximum band of frequencies whose low frequency "cutoff" limit is determined by the capacitance of its associated coupling capacitor and its load impedance. Generally, the highpass tuner is

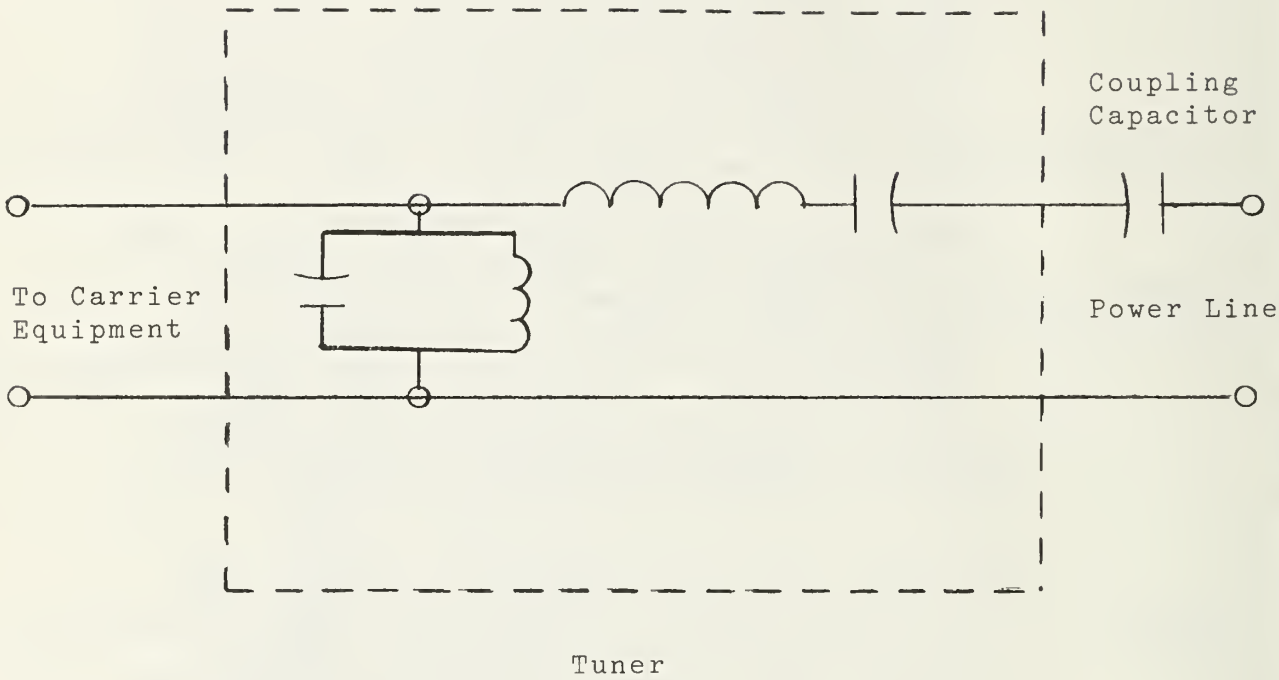
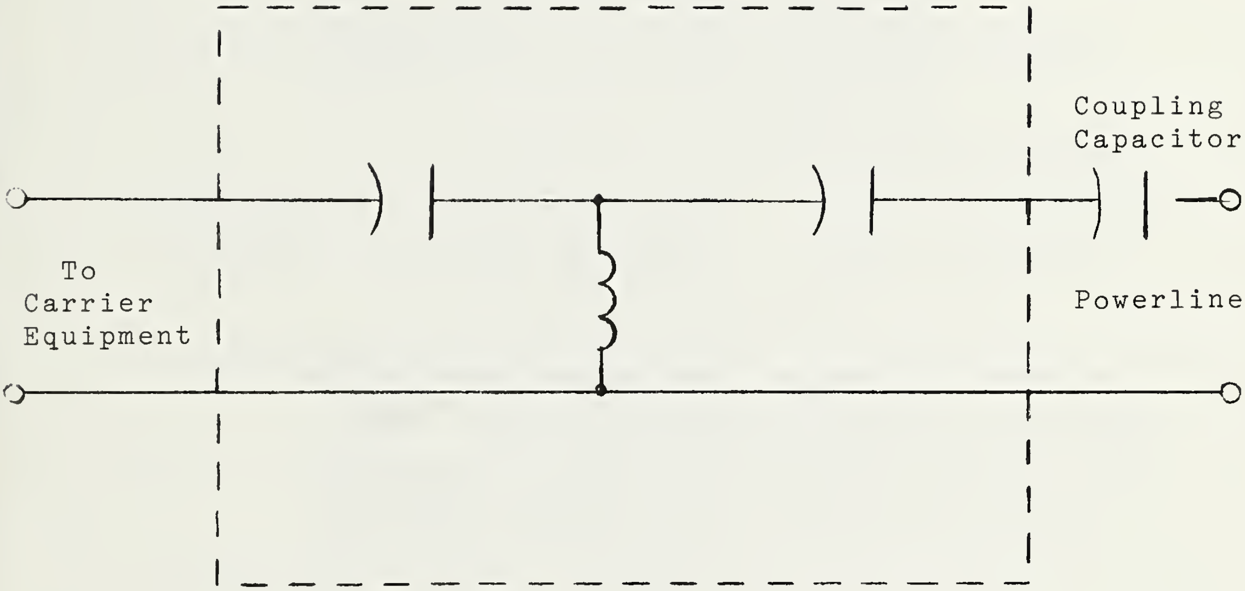


Figure II - 19

Simplified Bandpass Filter



Tuner

Figure II - 20

Simplified Highpass Filter

recommended where multi-frequency wideband types of equipment are desired over the single phase wire and higher frequencies can be utilized. For a specified coupling capacitance and line impedance, the low frequency cutoff for the highpass tuner is higher than the low frequency limit available with a bandpass tuner.

e. Line Traps

Line Traps are essentially tuned circuits used in power transmission lines for a variety of conditions. In essence, line traps provide a high impedance to the carrier signal while offering a negligible impedance to the normal 60Hz lines current. A line trap has various functions among which are:

- To retain integrity of PLC equipment in the event of open or short circuits on adjacent power line sections and during switched circuit intervals
- To provide for normal operation of transmission equipment when power line is grounded through traps
- To minimize interference effects from other carrier equipment
- To prevent excessive loss of carrier energy in connected facilities
- To attenuate carrier frequency reflections

A line trap's purpose may be said to make the power transmission line as transparent as possible to the communications equipment, especially during switching and fault conditions.

The electrical characteristics bearing primary importance on the selection and application of a line trap are inductance and impedance.

Values of inductance normally range from 0.265mH to about 2.0mH and depending upon the specific requirements, just above 2.0mH.

A PLC system coupled as shown in Figure II - 20 sees two possible transmission paths: down the transmission path, or through the line onto the station bus. If the impedance of the line trap is the same as that of the transmission line, the power is of equal division through each path. The larger the impedance of a line trap at the propagation carrier frequency, the less the signal is attenuated. The isolation capability of a line trap is dependent upon its impedance relative to the impedance of the transmission line.

The magnitude of the resonant impedance $|Z|$ for a single frequency line trap is given by the approximation equation $|Z| = Q\omega L$ where

Q = the ratio of inductive reactance of the coil to the total resistance of the circuit

$\omega = 2\pi f$ (where f is the resonant frequency)

L = inductance of the trap

If Q remains constant with frequency, the resonant impedance of a line trap is proportional to the inductance of the trap, and its resonant frequency. For frequencies sufficiently far off resonance, the magnitude of the impedance can be calculated from the approximate equation:

$$|Z| = \frac{\alpha \omega L}{\alpha^2 - 1}$$ and the phase angle from:

$$\tan \theta = Q \left(1 - \frac{1}{\alpha^2}\right)$$ where Q, ω and L are as previously defined and α is the ratio of the actual frequency to the resonant frequency

The impedance relationships of double-frequency traps are sufficiently complicated as to obviate their treatment herein. Rather, we use simple resonant circuit theory and solve for the impedance of each resonant frequency by taking one-half of the single resonant impedance.

It is necessary not only that the line traps have a high impedance at resonance, but also that the traps have a reasonably flat resistive component of the

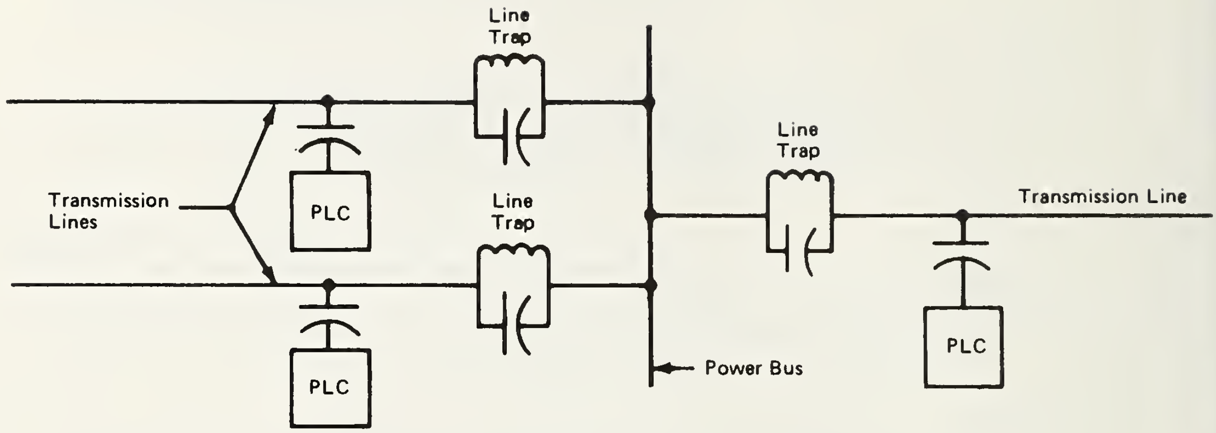


Figure II - 21 Utilization of Line Traps

bandwidth of the trap. This is accomplished with a low Q and wideband tuned traps. The result is that the impedance for a low Q trap has less pronounced peaks within the band, and all frequencies tend to be attenuated uniformly. The standard high Q traps have a high impedance at resonance and are therefore ideally suited to narrow band channels.

Traps manufactured today cover frequency ranges from 20 to above 300 kHz.

A single frequency line trap is shown in Figure II - 21 and is the simplest of the line traps used. The blocking band of the trap is the frequency range over which the impedance magnitude is not less than 400 ohms as shown in Figure II - 22.

A two frequency line trap as shown in Figure II - 23 has a bandwidth around its resonant peaks as shown in Figure II - 24. Failure to observe adequate frequency spacing in the order of 25 percent of the upper frequency, or 25kHz, whichever is greater, affects the impedance within the band. The result is that distortion will occur within the band.

Where it is necessary to trap frequencies closer than the previously recommended spacing of 25 percent, trapping may be obtained by tuning a single-frequency trap to the mid-point between the two frequencies of resonance or through the use of a wide band trap.

The wide band trap, Figure II - 25 contains a tuning device, and in conjunction with the inductance of the primary trap provides a wide bandwidth that does not require a field adjustment. The benefit here is that a wide range of frequencies (on the order of 100-110 kHz) may be accommodated with a single device.

The adjustable wide band trap is an adaptation of the fixed wide band trap and contains a tuning device which permits altering the blocking band to various frequency regions. It also permits selection of several impedance values to accommodate the characteristics of the line as shown in Figure 26.

By way of contrast, a self-resonant line trap is a line inductor without a tuning mechanism and resonates as a function of the distributed capacitance within the carrier band. This coupling method provides a better

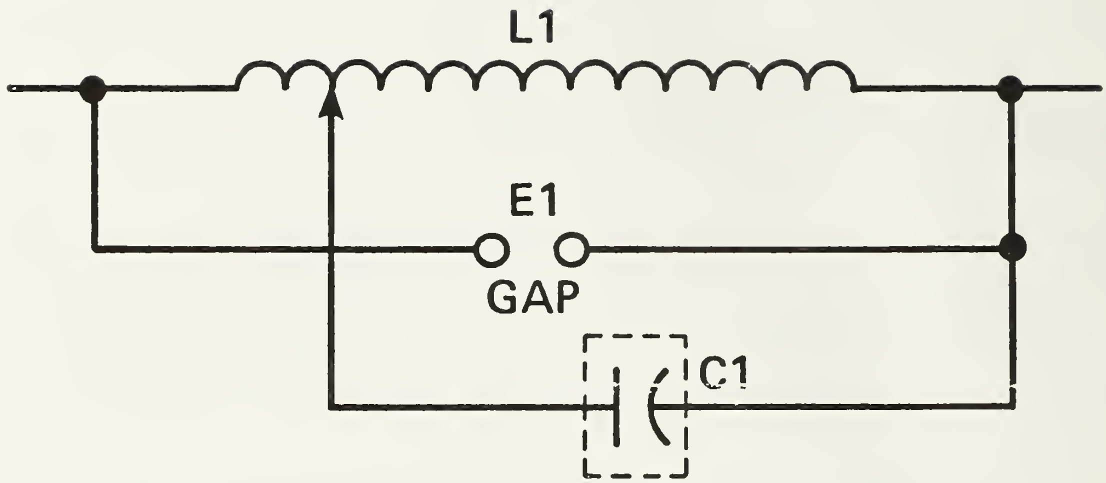


Figure II - 21 Single-Frequency Line Trap

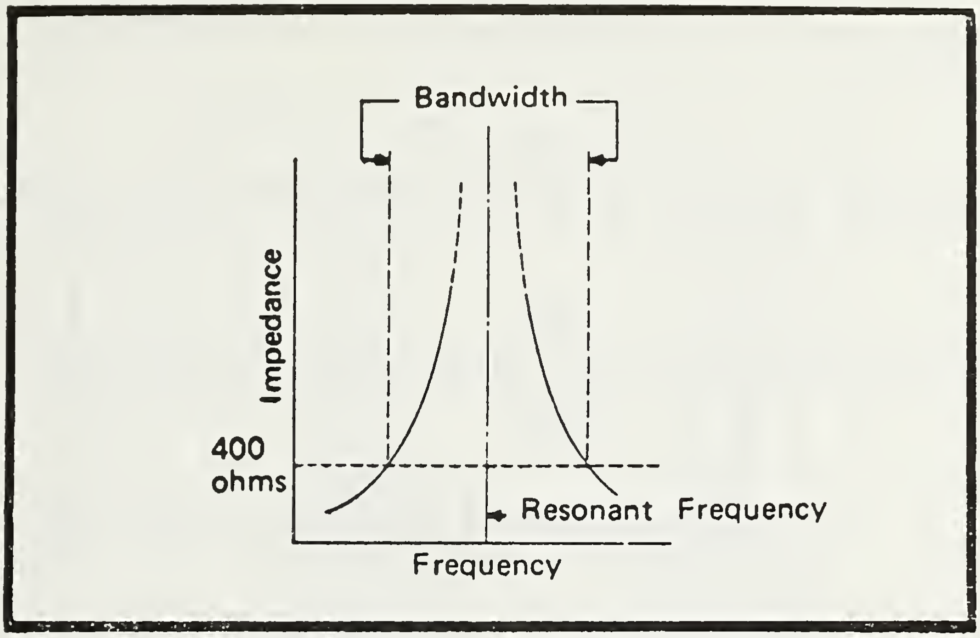


Figure II - 22 Response of Single-Frequency Trap

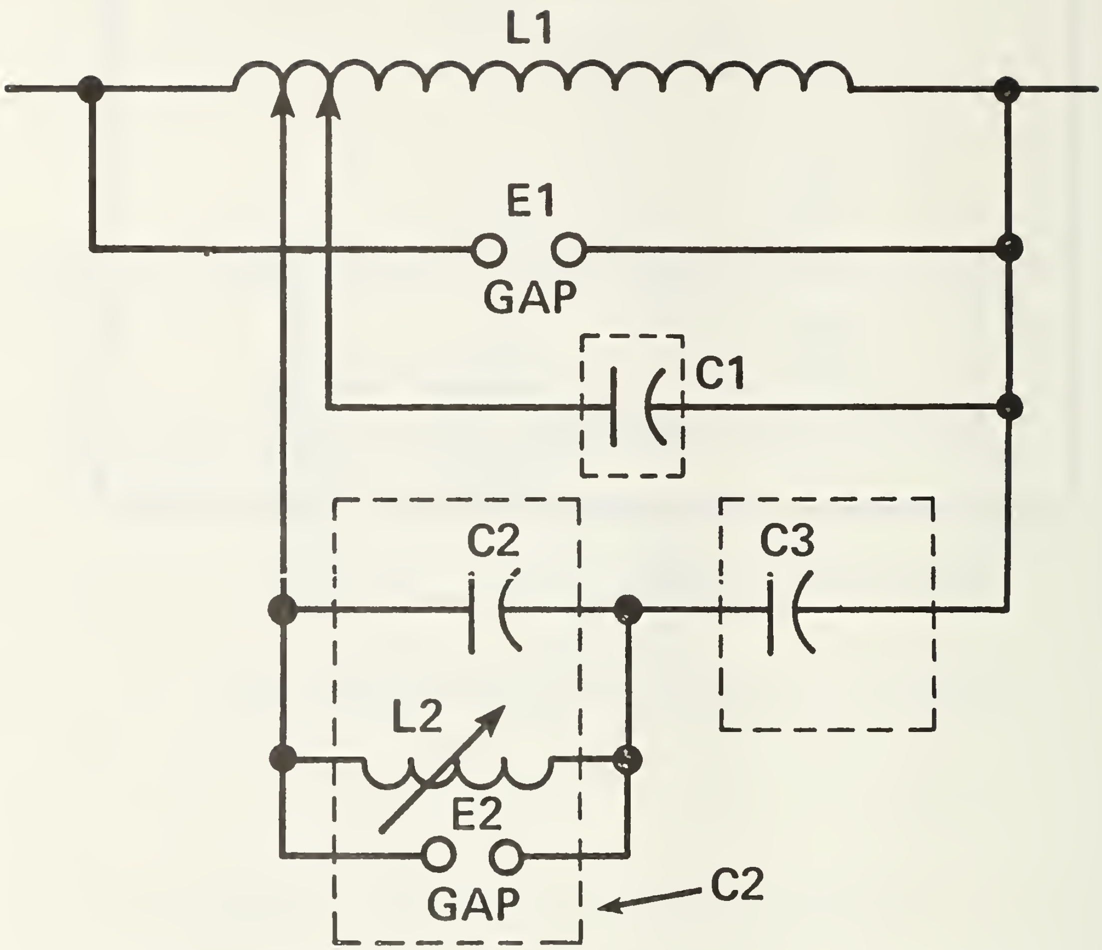


Figure II - 23 Two-Frequency Line Trap

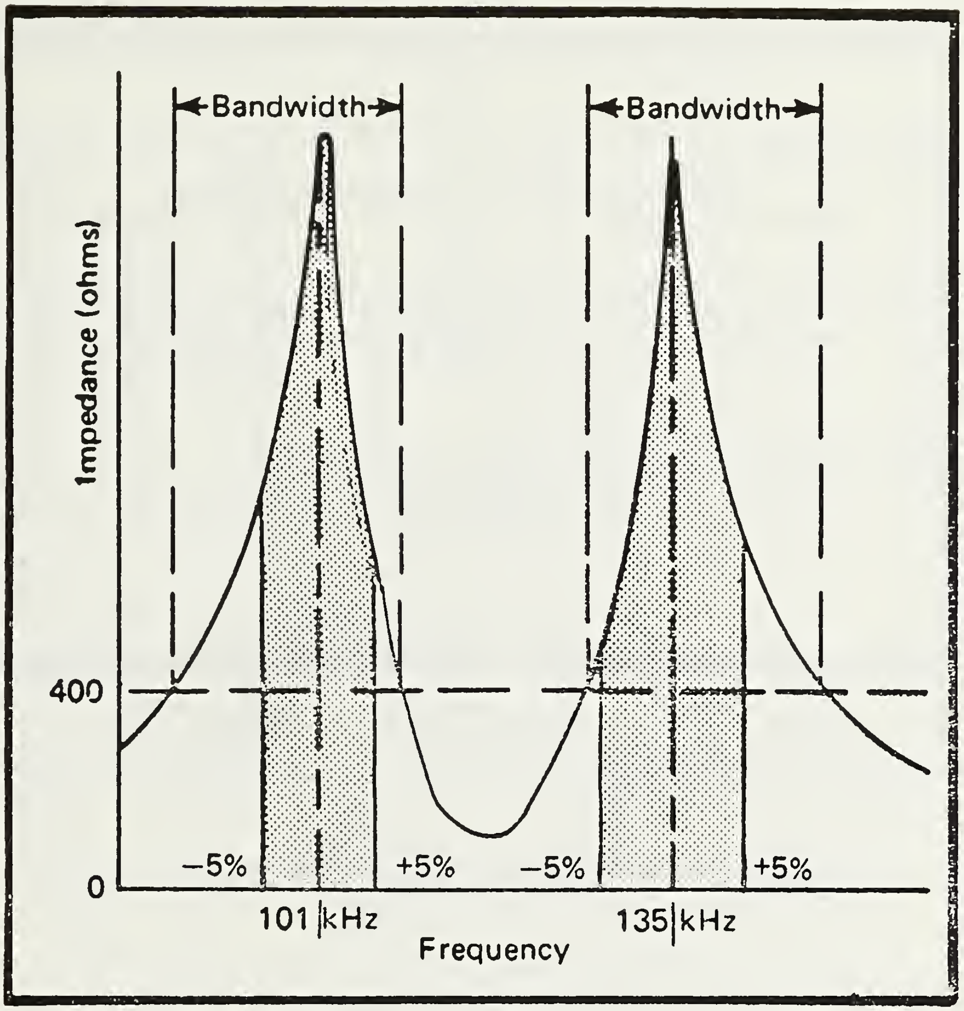


Figure II - 24 Response of Two-Frequency Trap Having Frequency Spacing Greater Than 25% and 25 kHz

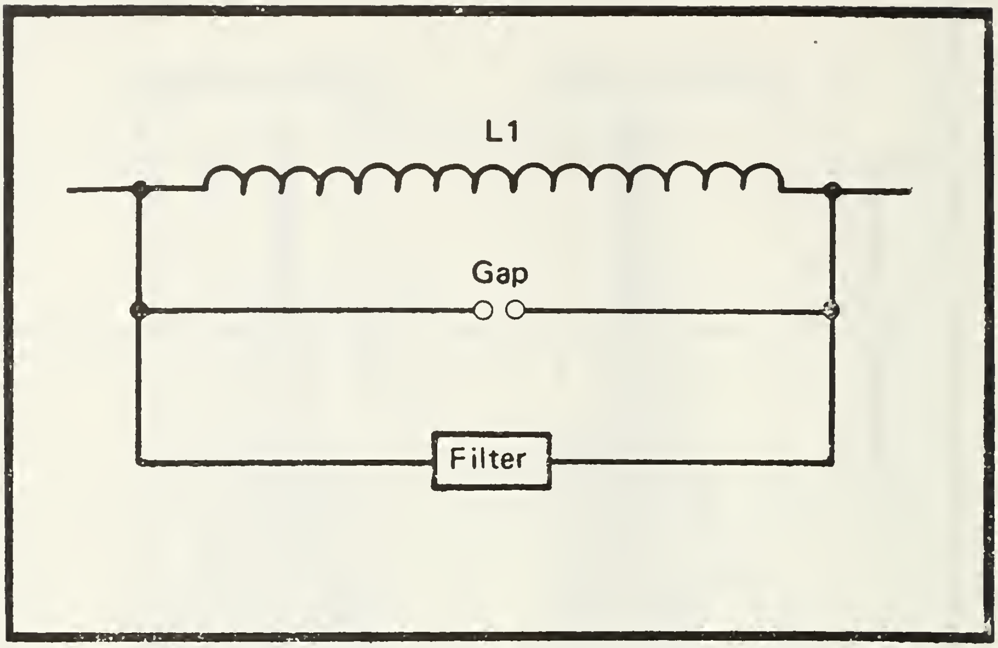


Figure II - 25 Fixed Wide-Band Line Trap

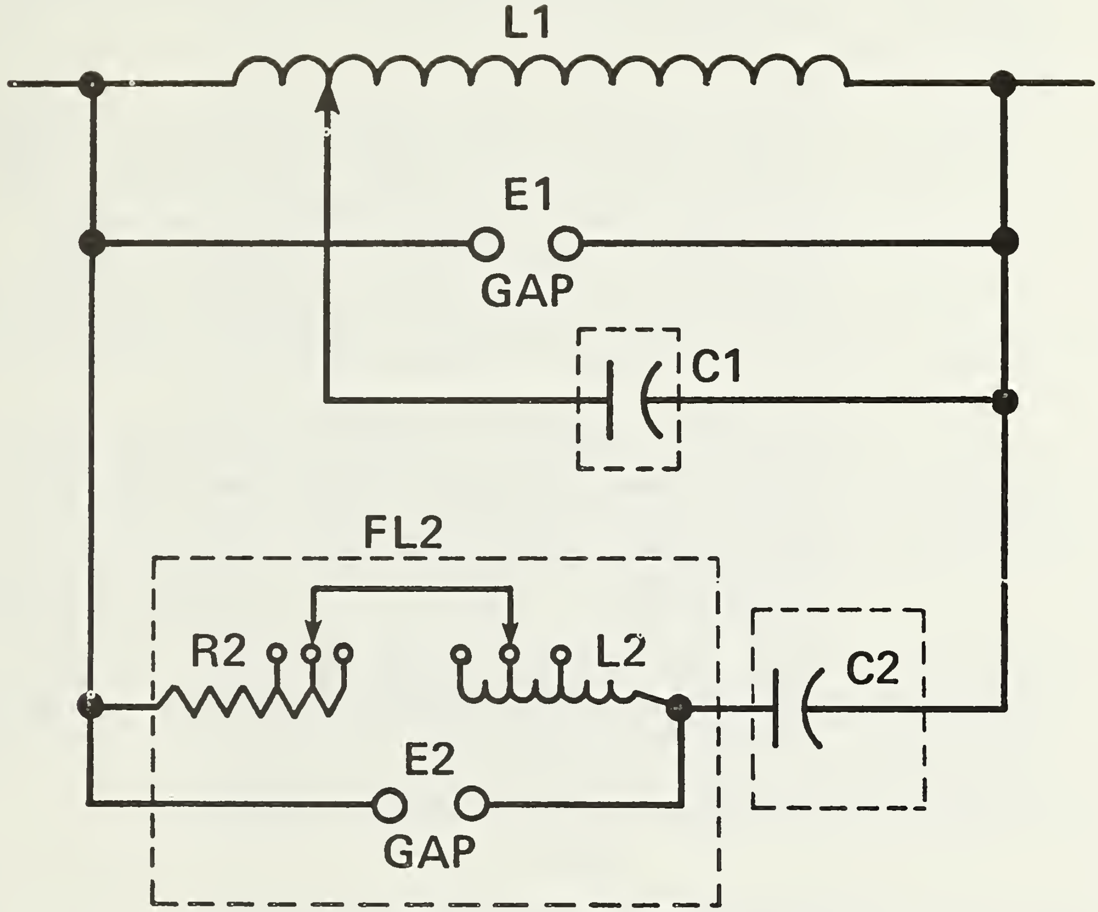


Figure II - 26 Adjustable Wideband Line Trap

pass band which is broader than that obtained with conventional wide band tuning. However, there is a drawback in using this device since the possibility of series resonance between the inductive reactance of the trap and capacitive reactance of the station bus exists.

Considering that a line trap has a finite impedance, a certain amount of the signal will be coupled to the station bus and possibly other lines terminating on the station bus. Therefore, there may be times when it will be necessary to trap all three phase conductors in order to obtain sufficient isolation. This is particularly significant when a transmission line is tapped at some point between two terminals.

The power frequency and mechanical aspects of line traps are delineated in IEEE, ANSI, and NEMA standards. Inasmuch as the line trap forms a part of the power circuit and carries line current, there must be a thermal current rating which is based upon a one second current carrying capacity measured in symmetrical rms amperes. Standard current ratings (main power coil) at the power frequency are: 400, 800, 1200, 1600, 2000, and 3000 amperes. Mechanical stresses are set up by the high currents and therefore a mechanical current rating of 2.5 x rms current rating is specified.

Table II - 7 lists the minimum requirements.

Table II - 7

Thermal and Mechanical Current Ratings

Ampere Rating	2 Sec. Thermal Current Rating Symmetrical RMS Amps	Mechanical Current Rating Symmetrical RMS Amps
400	15,000	15,000
800	20,000	20,000
1200	25,000	25,000
1200 (Heavy Duty)	42,000	42,000
1600	44,000	44,000
2000	63,000	63,000
3000	63,000	63,000

f. Filters

The most often used separation filter circuit is the simple series resonant L-C unit shown in Figure II - 27. This unit is a bandpass filter admitting the carrier frequency to which it is tuned and attenuating the other out-of-band frequencies. Such units are available as standard items from manufacturers of line tuning equipment. The bandwidth coupled into a 50 ohm coaxial cable circuit, as shown in Figure II -28 through a typical series L-C unit is a function of the L/C ratio and the resonant frequency to which it is tuned. In general, for a given center frequency, a higher L/C ratio provides increased selectivity at the expense of a higher insertion loss. As the requirements for frequency separation increase, and require either additional selectivity, or higher out-of-band impedance than simple L/C can provide, more elaborate means of filtration must be sought. Figure II - 29 is a circuit providing high pass/low pass filtering effectively isolating a portion of the desired band. The high pass/low pass filter application is especially useful when two PLC terminals are using the same wideband tuner and coupling capacitor.

Special purpose filters may also be required for attenuating disconnect-switch disturbances and other transients particularly harmful to communications circuits. Interference frequencies generated by arc noises are a function of the electrical length of switchyard bus segments connected to the arcing switch and range from 500kHz to 2 MHz.

Satisfactory reduction of high-noise effects on a receiver may be achieved by application of a highly selective bandpass filter in series with the coaxial cable connected to the receiver. Design parameters for highly selective constant-κ bandpass filters are influenced by extremely low-impedance shunt elements. The use of step-up impedance transformation alleviates the constraints due to the availability of very low-inductance units of adequate current rating. Components used in line tuning units are well adapted for construction of constant κ filters since the cases in the variable inductors are designed to let the coil carry relatively high currents with a minimum of saturation and detuning.

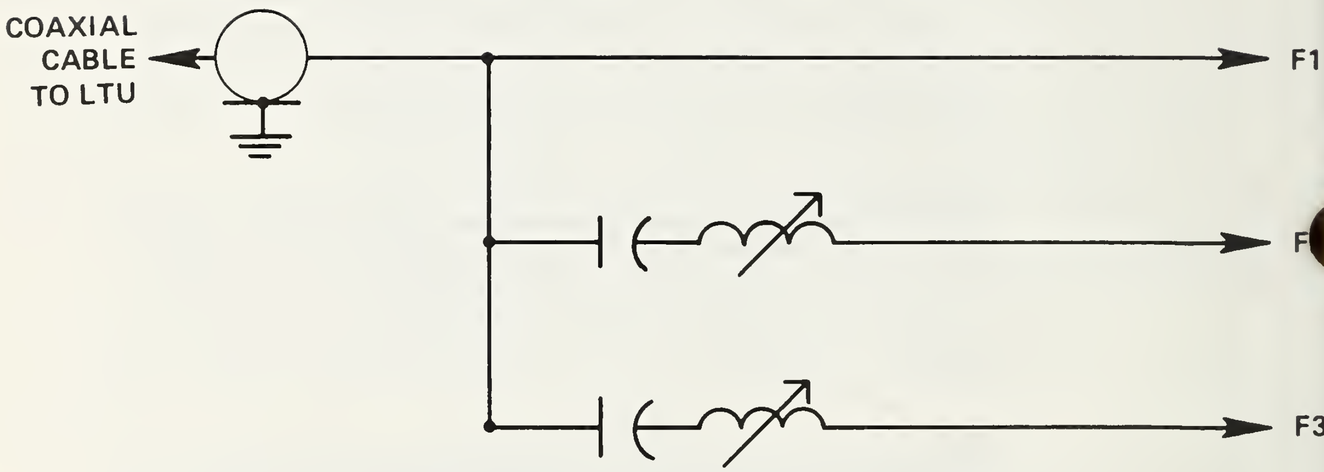


FIGURE II - 27 FREQUENCY SEPARATION WITH SERIES L-C UNITS

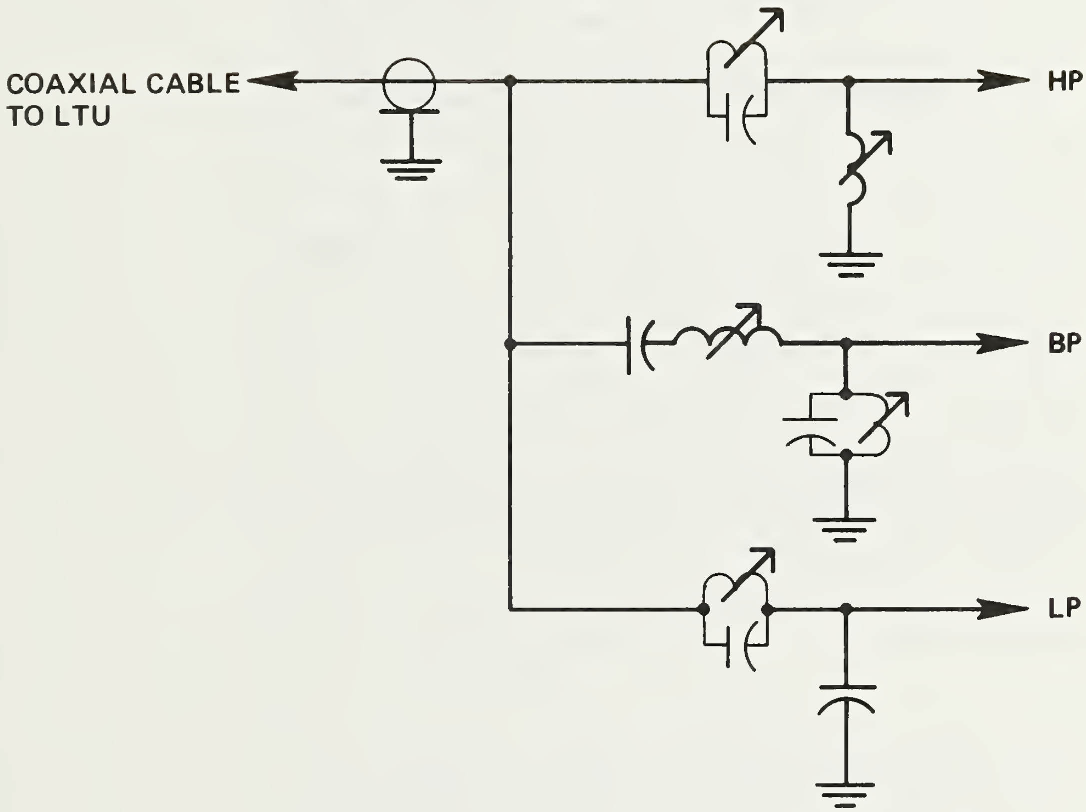


FIGURE II - 28 MORE COMPLEX SEPARATION FILTERS

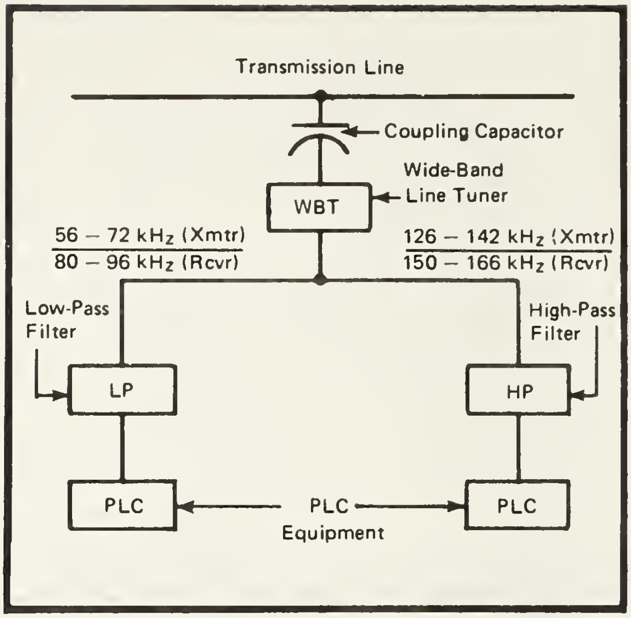


Figure II - 29 Typical Application of Low-Pass/High-Pass Filters

g. <u>Auxiliary Coupling Devices - Hybrids</u>

In instances when a transmitter is required to operate at a frequency very close to that of another transmitter or receiver, the selectivity offered by L/C filters is insufficient to provide the isolation required to eliminate, or reduce intermodualtion and interference. In such cases, a carrier frequency hybrid may be able to provide the necessary isolation between two terminals. A carrier hybrid is basically a balanced bridge in which a carrier signal applied to either input divides its energy between the line load and the balance network impedance. If the degree of balance is sufficient, the carrier signal voltage will be nulled at the opposite input. The total reduction in signal level from one input to the other is called the trans-hybrid loss. Balancing of the hybrid requires that the balanced network have an impedance characteristic which matches the line impedance at all frequencies within the range of interest. The closer this match, the more satisfactory the hybrid operation. Figure II - 30 is a typical hybrid configuration. The precision of balance achievable may be greater than 60dB between two inputs at a single frequency. This degree of balance may change from time-to-time as line impedance changes with temperature and other variable factors. The hybrid is often required to operate at two or more frequencies. A trans-hybrid loss of 20 - 25 dB or more is adequate for most purposes. In practice, it is generally possible to maintain a balance of 20dB or more at any frequency within approximately 3 percent of center. This frequency band over which a hybrid may maintain balance is called the bandwidth of the hybrid. The type of balancing network and adjustment methods affect the hybrid bandwidth. While the line impedance is the dominant factor in determining the hybrid bandwidth,all of the above factors are to be considered.

Some hybrids are arranged so that the balancing device in effect places a reactive matching section between the connected line impedance and a transformer with an adjustable impedance ratio. The "reflected impedance" presented to the hybrid's input windings is the same as though the line impedance were a pure resistance of predetermined value. A single fixed resistance in position of the usual balance network generally suffices. A significant result from this

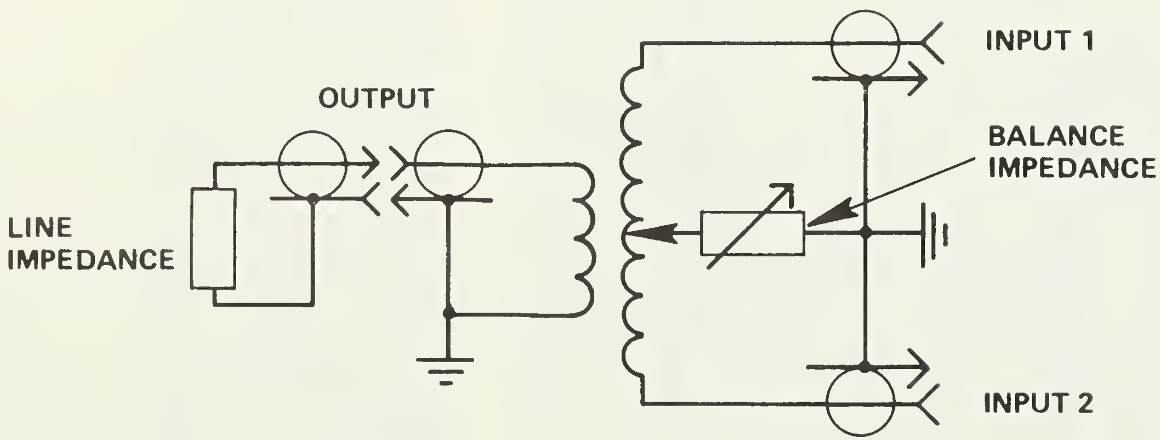


FIGURE II-30 HYBRID SCHEMATIC

method is that the impedance into either input of the hybrid has predetermined resistive value when the hybrid is balanced.

Several applications of the two primary types of hybrids--the reactance hybrid and the resistance hybrid are shown in Figures II - 31through II - 34.

Another type of hybrid, the skewed hybrid is used to isolate a transmitter from a receiver by providing a low insertion loss between the transmitter input and the line and a high insertion loss between the transmitter and receiver ports.

The highpass tuner has no theoretical upper limit. Highpass tuners also contain a matching transformer, protective gap and grounding switches.

3. Coupling and Trapping Circuits

The coupling of the carrier system may be accomplished in several ways. Basically, it involves connecting a current line inductor L_c between a phase conductor and its associated station bus. A coupling capacitor is connected from the line side of L_c to a tuning unit with an impedance matching device. Finally the carrier transmission equipment is connected with a short length of coaxial cable to the line tuning unit. In addition, a bypass capacitor C_b may be connected from the substation bus side of L_c to the carrier equipment depending upon the isolation method used to isolate the carrier frequencies from the 60Hz bus. This section discusses four possible configurations of coupling circuits as used in PLC systems.

a. Phase-to-Ground Coupling

In this arrangement, the carrier transmitter-receiver is connected between one phase wire and the station ground as illustrated in Figure II - 35.

The return path for the carrier is over the two other phase wires rather than the ground itself, and the presence of overhead ground wires helps to effect this transfer at the terminals. This is the most frequently used arrangement, since it requires only one coupling capacitor and one line trap per terminal. The capacitor should always be connected to the center phase wire, since the loss will be only slightly higher than the center-phase-to-outer-phase coupling. The

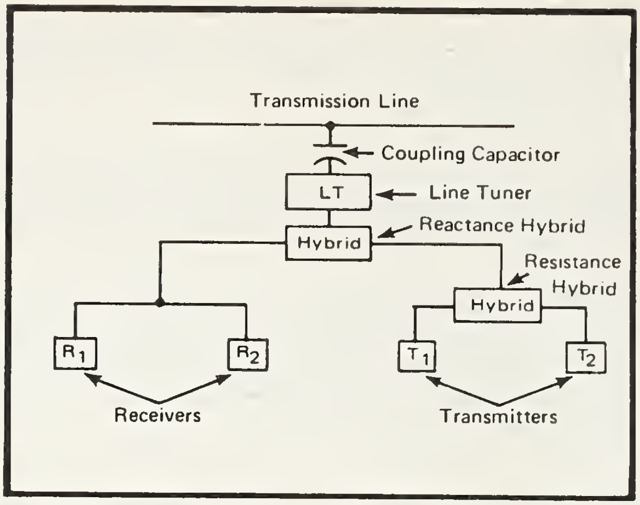


Figure II - 31 Bi-Directional Channel with Two Transmitters and Two Receivers

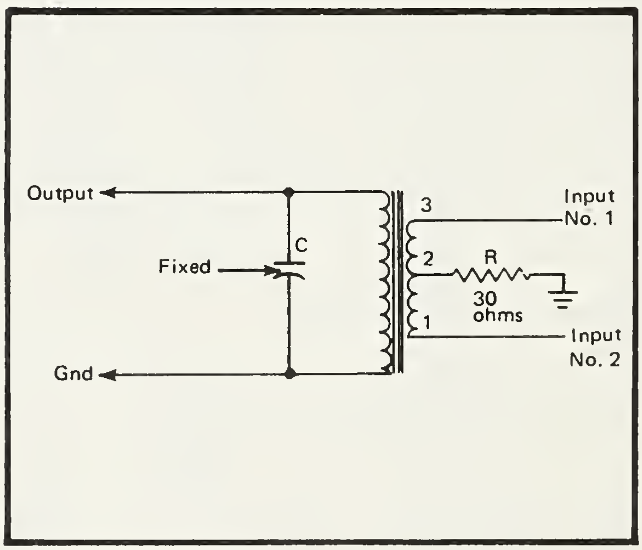


Figure II - 32 Resistance Hybrid

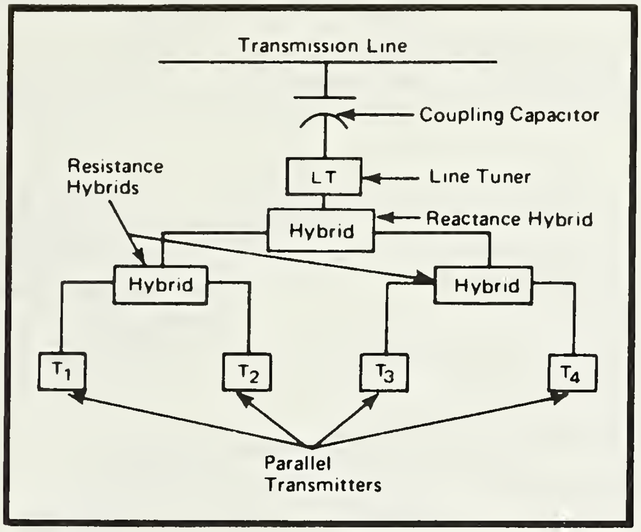
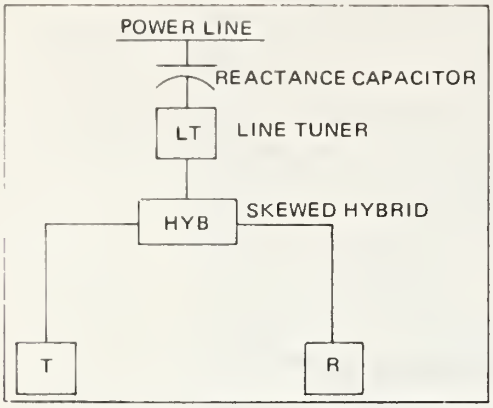
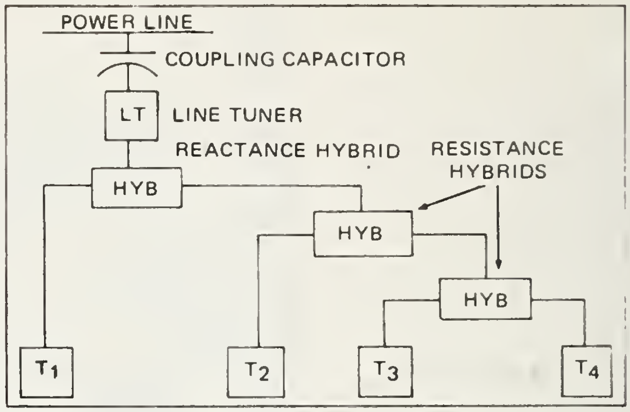


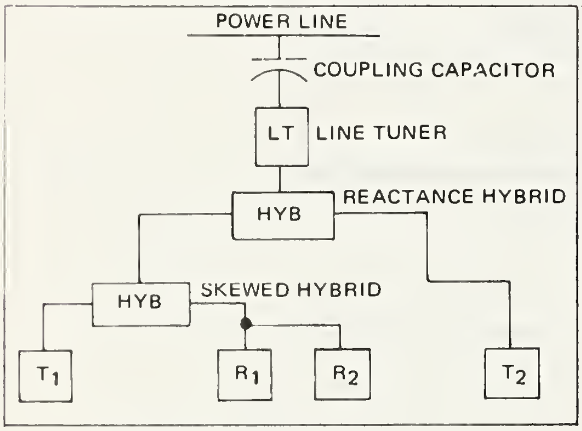
Figure II - 33 Typical Resistance Hybrid Application Between Parallel Transmitters



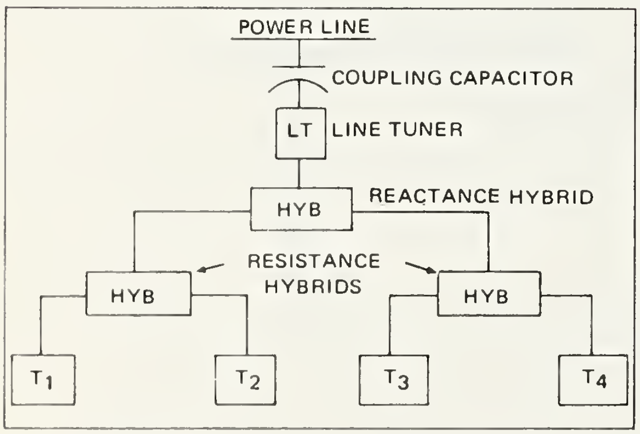
Bi-directional channel with hybrid to separate transmitter and receiver.



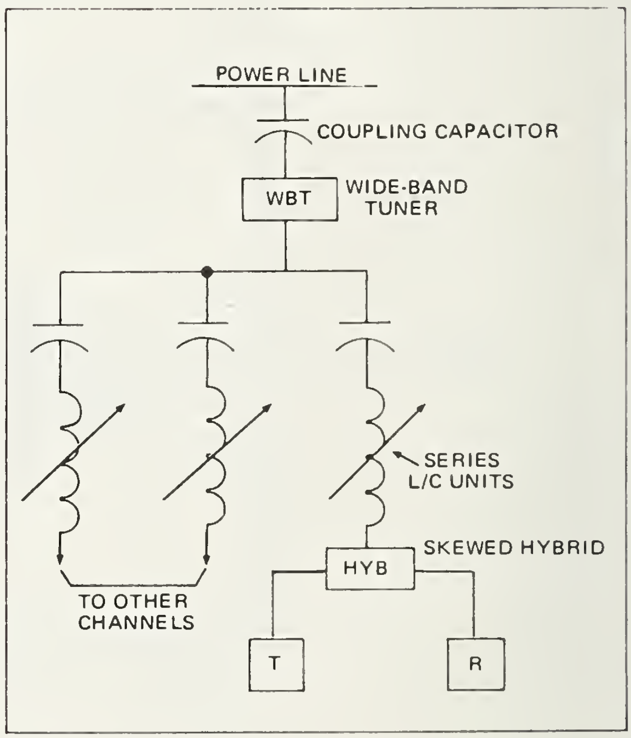
Use of hybrids between parallel transmitters arranged to favor transmitters No. 1 and No. 2



Bi-directional channel with two transmitters and two receivers.



Use of hybrids between parallel transmitters.



Use of hybrid with wide-band tuning

Figure II - 34 Typical Hybrid Applications

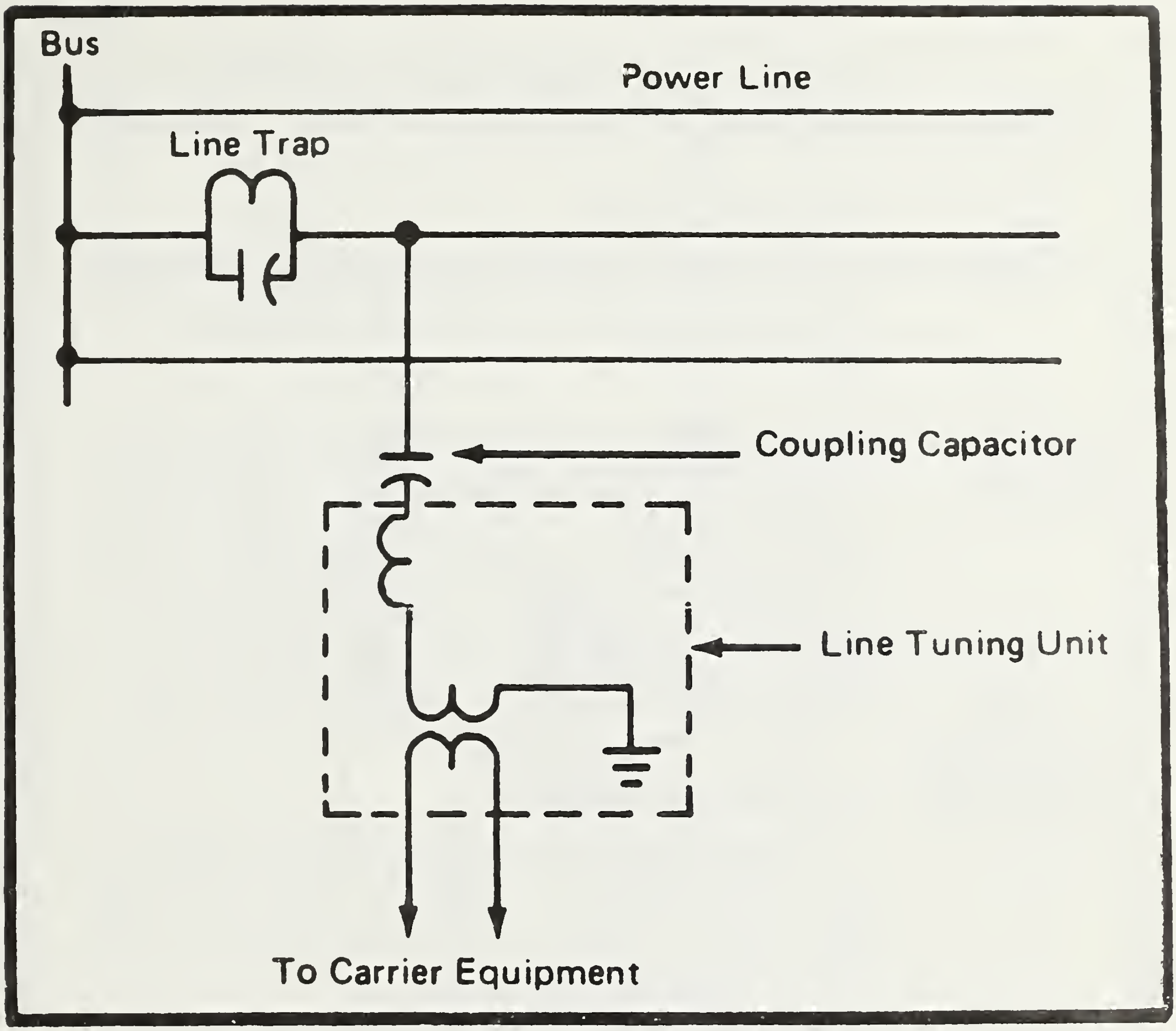


Figure II - 35 Center Phase-to-Ground Coupling

main disadvantage is that a ground or open of the coupled phase wire will cause a serious reduction in signal level.

Experience has shown that using the outside phase wire for line-to-ground coupling results in higher attenuation, and this should be avoided or used only on short lines.

b. Interphase Coupling

In this type of coupling, the transmitter-receiver is connected between two phase wires and operates essentially balanced to ground, as illustrated in Figure II - 36.

With the use of the interphase coupling unit, the coupling arrangement reverts to phase-to-ground when a short or open occurs on one of the coupling phases, and thus prevents the complete loss of signal. The lowest attenuation is produced when coupling is made to adjacent phase wires, i.e. center-to-outer. This arrangement can be coupled between the two outside phase wires and operated completely balanced to ground (true Mode 2 on a horizontally spaced transmission line); however, the attenuation then will be higher.

c. Intercircuit Coupling

The basic difference between intercircuit coupling and interphase is that coupling is made to one phase wire of one line and to a different phase wire of the other line of a double circuit power line, as illustrated in Figure II - 37.

With the use of intercircuit coupling, the arrangement reverts to phase-to-ground coupling when one of the circuits is open or grounded. This is the main advantage, since one line can be taken out of service and grounded while the carrier path remains over the other, however, there is an increase in attenuation for this condition which may be as much as 12dB.

A disadvantage of the configuration as shown in Figure II - 37 is the physical location of the coupling unit with respect to the two coupling capacitors. The cabinet containing the coupler is normally mounted beneath one of the coupling capacitors, with the second

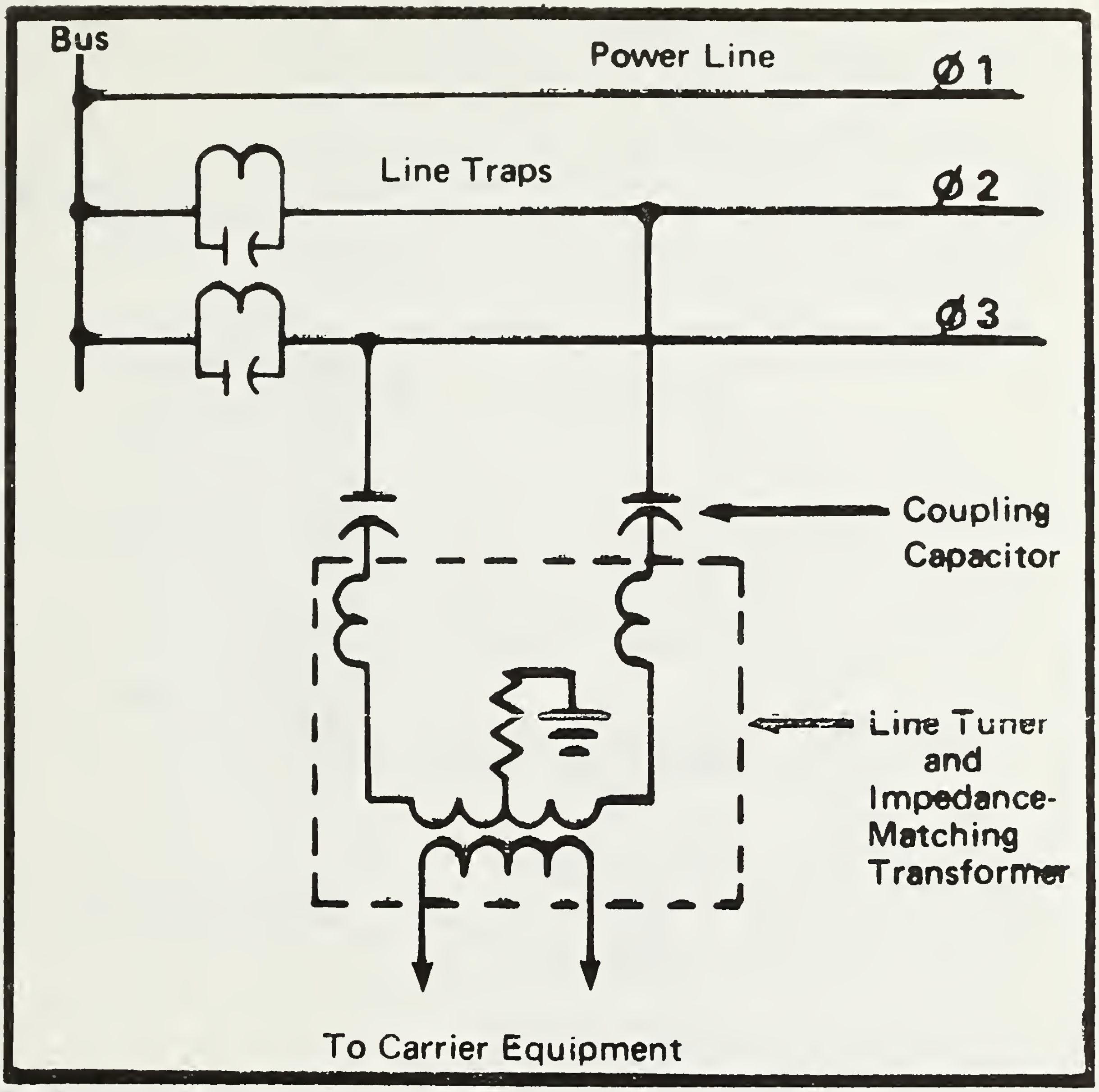


Figure II - 36 Center Phase-to-Outer Phase Coupling

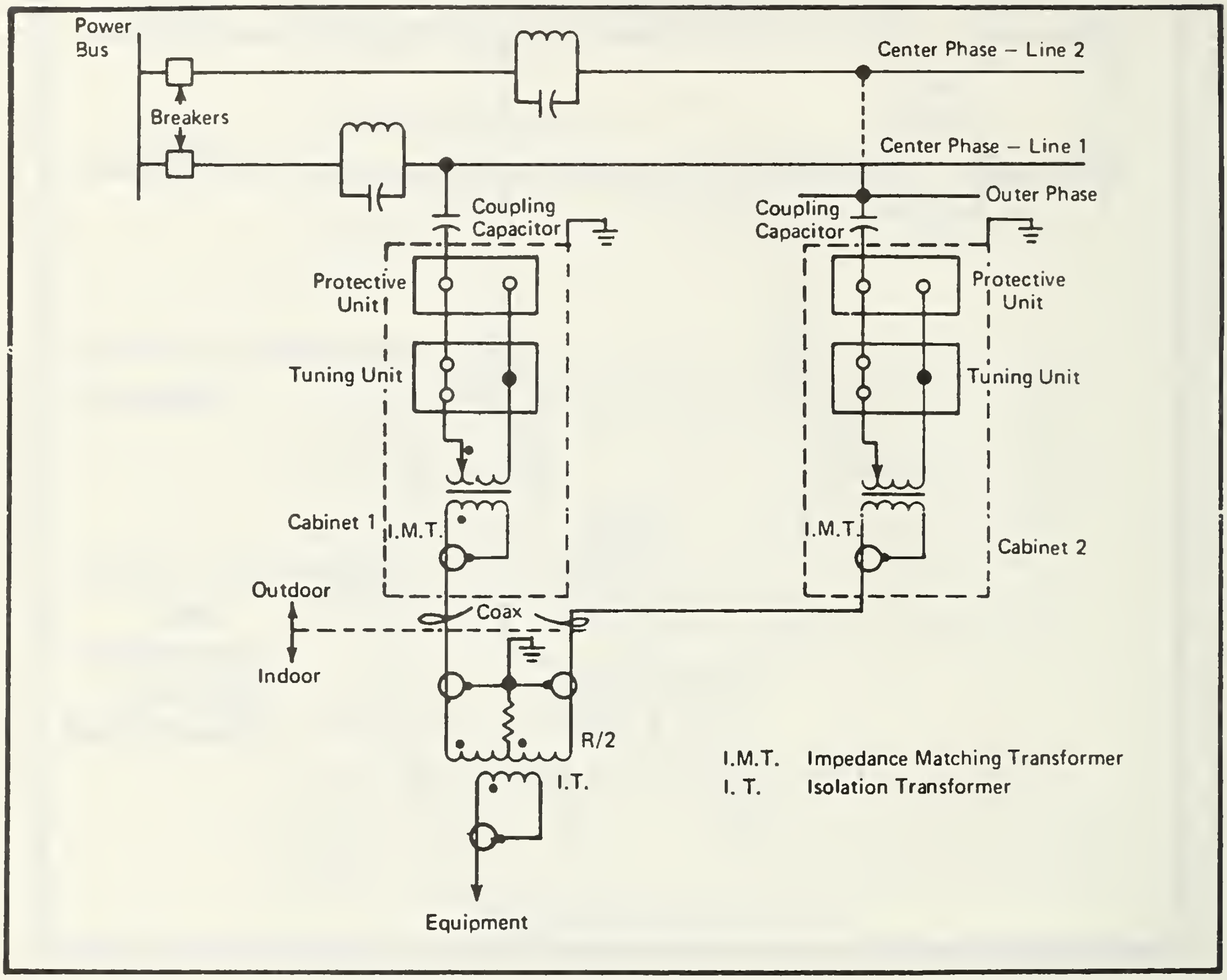


Figure II - 37 Intercircuit Coupling

coupling capacitor connected to the coupler by an overhead insulated cable. This overhead cable and its supporting structure may restrict the movement of vehicles inside the substation. When this situation exists, a two cabinet arrangement of that coupler may be used as shown in Figure II - 37. The configuration as shown in Figure II - 37 is advantageous in that an open or short circuit in one of the cables extending from the indoor equipment to the two couplers will not result in a communication outage. The system would automatically revert to phase-to-ground coupling over the other cable and its associated power line.

d. Mode 3 Coupling

The lowest line attenuation results when true Mode 3 coupling is used. In this case, the transmitter/receiver is connected between the center phase wire and the two outer phase wires, which serve as the return circuit. Due to its higher cost, Mode 3 coupling is usually used only on critical service lines or long EHV lines.

The Mode 3 coupling configuration shown in Figure II - 38 has two advantageous features that should be noted:

- Impedance matching is done in the low impedance portion of the system. Proper impedance matching, which results in proper Mode 3 voltages, is obtained using standard RG-8U coaxial cable

- Because all three phases of the power line are used to transmit the carrier signal, additional redundancy exists and better performance is achieved during power system disturbances. An open or short in one coaxial cable does not result in communication outage. The system automatically reverts to phase-to-ground coupling. (additional loss will be incurred when this happens.

Again, Mode 3 coupling is recommended for the most critical applications and on long, series-compensated EHV lines where system protection is paramount.

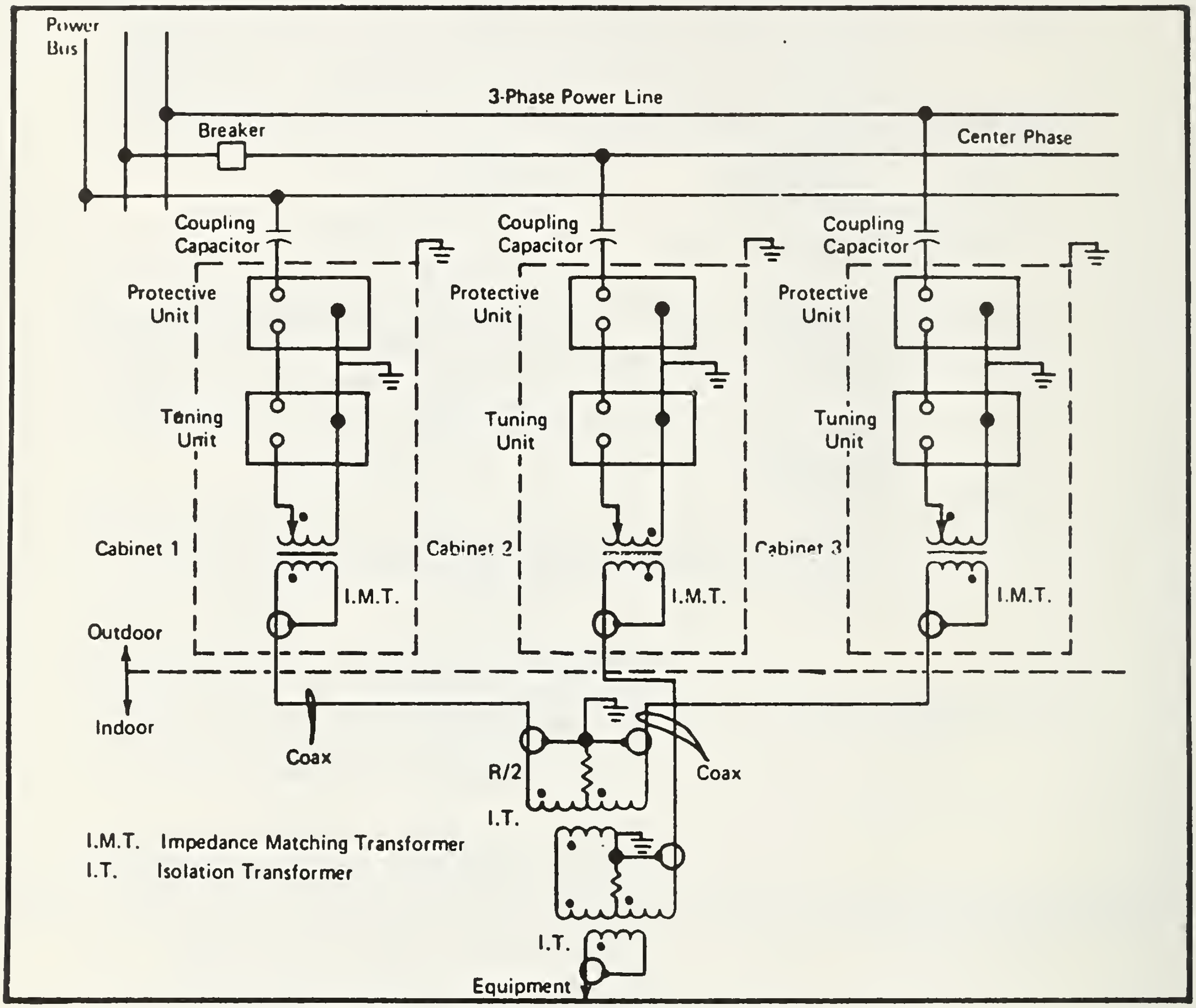


Figure II - 38 Modal Coupling

4. Facility Design Requirements

The facility Design Requirements which we will address in this bulletin are those which are associated with the PLC and ISW equipment which will provide the communications media for the user (borrower) power systems.

The subject addressed herein relates to a microwave inter-circuit with the PLC/ISW facilities since, in most cases, the power generation and distribution facilities will already be in existance when a determination is made regarding the facility design requirements.

a. Data Gathering and Survey

In any instance wherein a communication system is to be established, there are a number of items to be determined, and a number of functions to be carried out to establish the numbers and types of facilities required to house and operate the system in connection with the system operational specifications established by the borrower.

A considerable portion of these items are determined, with functions carried out under the Site Survey portion of the systems engineering and design phases.

The establishment of a communications facility on a virgin, or untouched piece of real estate requires that the design engineer determine the following in order to effectively and practically complete the total system design and effect construction:

- The suitability of the proposed site acreage for the intended facility, i. e., will the proposed site, when cleared of all local obstacles (trees, etc.), provide the optimum in site suitability

- Can the site be readily adapted to the system needs within the proposed budget for the system? In other words, what has to be effected at the site to render it useable for the communications facility to be established thereon?

- What are the access requirements in connection with the selected site?

- Are there existing, adequate roads leading to the site, or are new access roads required?

- Is there adequate and reliable power readily available at or near the site to support the total site requirements, or do additional or new power support facilities have to be provided?

- What are the normal weather ambients existing at the site area? Is there heavy rainfall for prolonged periods of time at, or near the site area? How about snowfall during the winter months? Will access to the site in winter months be difficult, with access having to be provided for?

- What types of trees and forests are adjacent to the site, and along the proposed signal beam path? What obstacles exist along the path that could be detrimental to the system as proposed, or cause additional facilities to be added to the system to assure system operation and reliability

- What does the path profile look like? In the case of say a Microwave system, is there Line of Sight (LOS) along the total path?

- Are there water facilities, or water itself, available at or near the site area?

- Can adequate support facilities for both the equipment and personnel be readily and economically established on the selected site?

- Is the site located in an area that might be affected by other communication or electronic sites located adjacent to, or in the near vicinity of the station?

- Are there other logistic support items such as fuel, supplies and materials readily available to the site area, or do they have to be brought in from great distances?

- Is the site ground elevation the highest in the area, so that minimum tower heights will be required to mount any system antennas?

- Can the site be effectively secured to assure continued operation, free from outside interferences?

These constitute some, but in some cases, not all of the items to be determined by the site survey actions, all of which are important, to the final design and establishment of the communications facility. Without total knowledge on all of these items, it is impossible to design and construct an adequate, functional communications facility or system.

b. Equipment Considerations

A very important item associated with facility design is the complete knowledge of all the inherent characteristics of the equipment to be installed within the facility. This includes, but is not necessarily limited to:

- The family of communications equipment

- Prime power equipment (if same is to be generated on site)

- Standby power or Uninterupted Power Supply (UPS) equipment (if needed or installed)

- Power distribution equipment and lines

- Water supply and distribution equipment (if needed for equipment operation)

- Commonality of equipment and the ability to locate items within

the facility without adverse interference between items of equipment

- Environmental requirements for efficient and reliable equipment operation

- Lighting equipment and density of illumination

- Ancillary equipment racks, communications and power cable distribution, in-plant and outside plant

- Distribution and Main Frame requirements

- Equipment power consumption, and power stability requirements

- RFI and EMI considerations and protection

c. <u>Design of Facility</u>

The final design of the communications facility comes about after a complete gathering of all technical data on the system equipment, weather and environmental conditions, geographic and site location, support logistics, to include power, water, fuel, utilities, etc. has been accomplished, and the design engineers can proceed to design a complete, practical, and effective communications system.

As stated earlier, all of the items of survey mentioned above are always done in the instance of establishing a complete new communications facility, but the determination of much of the above data as applies to a PLC or ISW communications facility, in instances where the power system plant facilities are already "in-place", is just as meaningful and required, regardless of the extent of the communications system, in order for the PLC or ISW system design engineer to provide an effective, practical, and reliable PLC communication system.

The sequence, or extent of a communications survey for a PLC system may not follow, or be as extensive as that effected in connection with a virgin communication facility, but it is every bit as important and necessary as those used for establishing virgin site facilities.

c. <u>Grounding</u>

The grounding of any communications system is one of the prime factors considered in the design of any facility. A station with a ground system with minimum resistance to true earth, is a system (with all other factors being equal, and taken into consideration) which will serve to eliminate many sources of noise in the communications equipment and system.

Grounding of any communications system should include; a station signal ground, station power ground, and a protective ground.

(1) <u>Station Signal Ground</u>

The station signal ground should be separate from all other grounds as the station, should be connected to all equipment which carries a communications signal on it. should be so constructed as to contain no "ground loops", and should be terminated (separately) at a station signal ground plate with minimum resistance to true earth. Under normal engineering design a resistance of no more than 5 ohms to true earth should be striven for.

If a resistance in this category is not readily obtainable in or immediately adjacent to the station, a grounding point should be constructed using artificial means. This is to say that a hole should be excavated (within the limits available), to provide at least 25 square feet of earth contact, fitted with a grounding plate, back filled to cover the plate, and provide a means of keeping the earth wet at that point to maintain the established resistance.

In an instance such as this, saltpeter should be mixed with the soil to assist in getting the desired ohmic resistance.

(2) <u>Station Power Ground</u>

The station power ground is usually the neutral wire of the power system feeding the communication equipment of the PLC facility. It is never connected to the station signal ground, and is usually terminated at the primary power source for the station. All power grounding should be terminated at this point.

(3) Station Protective Ground

This ground is established at communications stations to protect the station operating personnel from stray voltages which may exist on the installed station equipment.

In communications parlance (mostly in Government systems) the protective ground is the "Green Wire". The third wire in a single phase circuit, and the fourth wire in a three phase circuit. All communication equipment should be grounded on the cabinet with this protective ground connected to all overhead racks, etc., and terminated on a power panel inside the station, then taken (through the station wall) immediately to ground at the nearest point. In no case should the protective ground come into contact with the station signal ground.

(4) Site Development

In the instances of PLC systems communications sites, the amount of site development necessary is dependent on two things; whether the power site (substation or otherwise) is in being, or whether the site is a virgin site. In the case of an "in-being" site the only development to be accomplished is that necessary to adapt the communication equipment to the existing facilities.

In the instance of a virgin site, all of the above listed items should be taken into consideration in the development of the site.

(5) Site Plan

The accomplishment of the site plan for the PLC site follows much the same as that stated above for Site Development. In the case of the "in-being" site, just add the communications equipment to the site plan, and for the virgin site, complete an entire site plan for all of the facilities located thereon.

(6) Power Supply and Distribution

Power supply and distribution for any family of communications equipment is one of the most important factors to be considered in the design

engineering and installation phases for the facility. Distribution facilities must be regulated from the power source to the power panel serving the equipment, to minimize loss, and from the power panel to the equipment. Loss from the power source to the panel should be held to about 10%, and from the power panel to the equipment to about 1.5%. All power should be rigidly regulated to assure continuous communications, and to avoid damage to equipment from spurious or extreme power anomalies.

F. System Operating Parameters:

The design of a communications system utilizing PLC and ISW as a transmission mechanism is more of an art than most other branches of communications, considering the entire range of disciplines involved in engineering an effective system.

The material covered in this section is representative of the parameters to be considered in the design of PLC and ISW systems.

1. Transmission Line Characteristics

In normal transmission line theory where conductor size, condition of the line, line spacing, height above ground, shunt path resistance, and ground resistance is constant, the configuration of the equivalent circuit is simple, and the characteristic impedance, loss, and other characteristics of the line can be easily calculated. In the case of PLC and ISW systems, where the power line is the transmission mechanism, the characteristics of the line vary enough to effect a poor correlation between calculated values and actual measurements. Consequently, measured data from typical lines are used for estimating line characteristics in these applications.

Three types of transmission lines are used in PLC communications: overhead power lines, high voltage power cables, and insulated shield wire (ISW). A fourth type of line--coaxial cable-- is used for connecting the carrier equipment to the transmission line. The characteristics of each type of line will be discussed in this section.

a. Overhead power lines are power transmission lines capable of passing voltages from 14kV to 500kV. Lower voltage lines, typically from 14kV to 230kV, have much smaller conductors with corresponding higher resistance, and higher attenuation. Lines in the 300kV to 500kV

range usually use bundled conductors with lower resistance at carrier frequencies. Bundled conductors are two or more conductors per phase at the same potential, serving as one conductor of the line.

(1) Attenuation

The attenuation of overhead power lines at carrier frequencies is a function of several important factors, including: frequency, line voltage, conductor size, and method of coupling. Phase to ground coupling is the most commonly used method for connecting carrier equipment to the lines. With this method, a single conductor of the power line acts as one leg of the carrier circuit, with ground as the return path. This system requires less coupling equipment (coupling capacitors, line traps and tuners) than the other methods of coupling and it is used for short haul, point-to-point channels, for such functions as relaying.

Table II - 8 presents approximate line attenuation for phase-to-ground coupled power lines ranging from 14kV to 500kV and from 40kHz to 300kHz.

Table II - 8

APPROXIMATE LINE ATTENUATION
dB per 100 MILES
PHASE-TO-GROUND COUPLING

LINE VOLTAGE kV	FREQUENCY kHZ						
	40	50	100	150	200	250	300
500	2.7	3.24	5.24	7.18	9.18	11.45	13.72
345	3.6	4.32	6.98	9.58	12.24	15.26	18.29
230	3.9	4.68	7.57	10.37	13.26	16.54	19.81
161	4.2	5.04	8.15	11.17	14.28	17.81	21.34
138	5.0	6.0	9.7	13.3	17.0	21.2	25.4
115	5.55	6.66	10.77	14.76	18.87	23.53	28.19
69	6.0	7.2	11.64	15.96	20.4	25.44	30.48
34.5	7.3	8.76	14.16	19.42	24.82	30.95	37.08
14	7.8	9.36	15.13	20.75	26.52	33.07	39.62

To fully utilize Table II - 8 , the attenuation figures shown must be modified by a correction factor to compensate for the coupling technique used. These correction factors are shown in Table II - 9 .

Table II - 9

Correction for Coupling	
Type of Coupling	Correction for Two Terminals
Center phase to outer phase	Add 0 dB
Outer phase to outer phase	Add 15dB
Center phase to ground	
No ground wire	Add 8dB
Steel ground wire	Add 4dB
Aluminum ground wire	Add 2dB
Copper ground wire	Add 2dB
Outer phase to ground	
No ground wire	Add 16dB
Steel ground wire	Add 12dB
Aluminum ground wire	Add 10dB
Copper ground wire	Add 10dB

(2) Characteristic Impedance

The characteristic, or surge impedance of a transmission line is the input impedance of the line. The characteristic impedance of a circuit consisting of a single conductor with a ground return is,

$$Z_o = 138 \log \frac{2h}{r}$$

where:

Z_o is the characteristic impedance in ohms,

h is the height above ground of the conductor,

and, r is the radius of the conductor in the same units

With overhead power lines, the characteristic impedance varies with the number of conductors in the line, the conductor size and spacing, and height above ground. The characteristic impedance

of different types of overhead power lines using phase-to-ground coupling is presented in Table II - 10.

Table II - 10

Typical Surge Impedance for Overhead Power Lines
Phase-to-Ground Coupling

Type of Conductor	Characteristic Impedance
Single Conductor	350-500ohms
Bundled Conductors,2 wire	250-400ohms
Bundled Conductors,4 wire	200-350ohms

To achieve the best coupling efficiency, it is necessary that the carrier coupling equipment be adjusted to "match" the particular value of surge impedance for the type of conductor used.

(3) Line Noise

Transmission line noise is an important factor in power line carrier since the quality of the carrier channel is dependent upon the signal-to-noise ratio at the receiver. Noise values for different transmission lines under fair and adverse weather conditions are presented in Figure II - 39.

b. High Voltage Power Cables

Power cables, because of their high voltage construction, serve as an excellent medium for communications. Each phase conductor is a power cable enclosed in a metallic shield which is connected to ground so that direct coupling between a conductor and ground is possible. In this way the characteristics of each phase are independent and, of most importance, the cable conductors are not subjected to the same sources of noise that plague overhead lines.

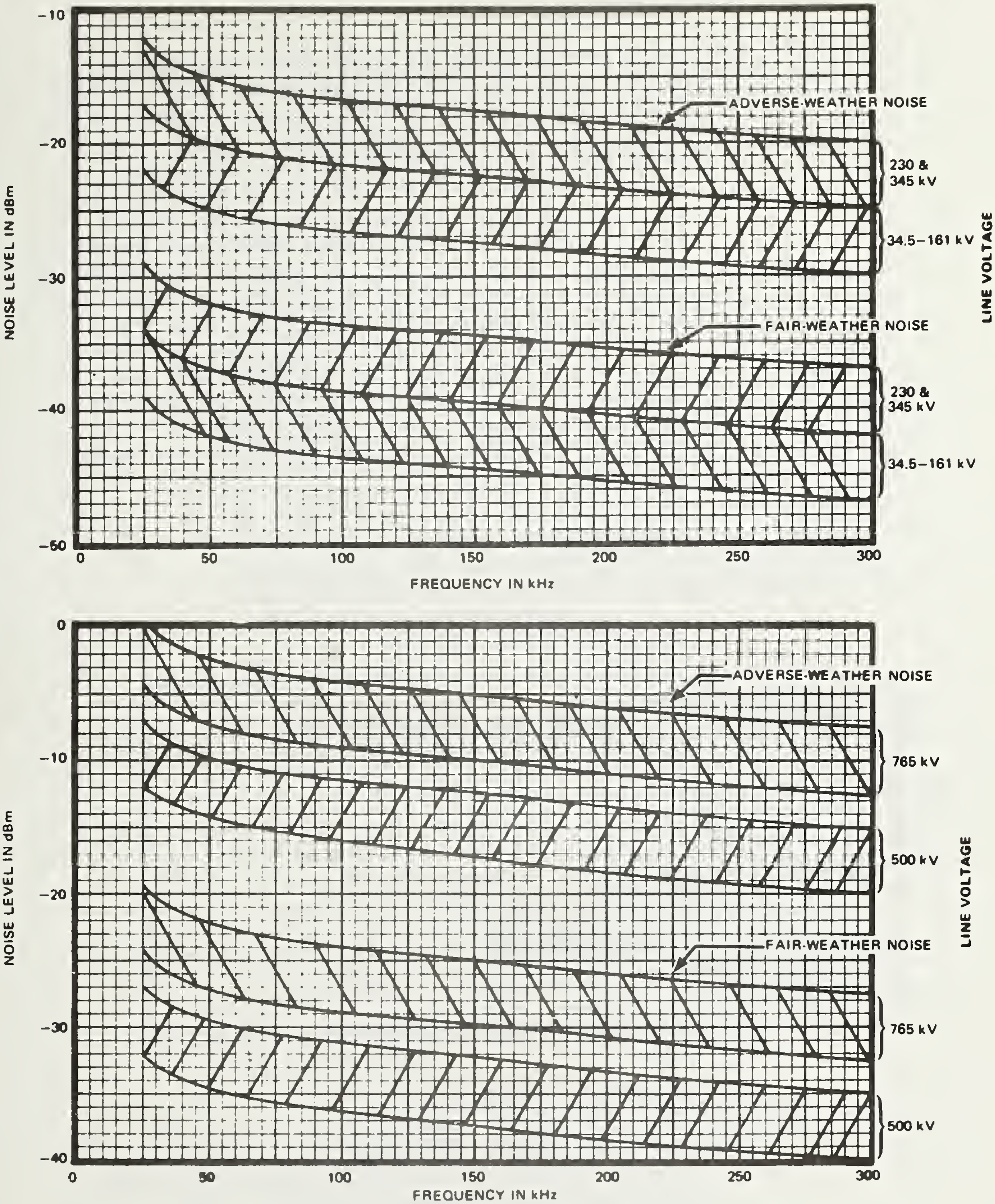


Figure II - 39 Transmission Line Noise Levels

(1) Attenuation

Transmission losses in power cable vary greatly depending on the construction of the cable. Single conductor power cables with grounded sheaths exhibit reasonably low transmission losses. For practical applications, single-conductor power cables with grounded sheaths are assumed to have the same values of transmission loss as RG-8/U coaxial cable. With pipe-type cable, transmission loss varies with the type of construction. Pipe-type cables incorporate shield tapes which are specially wound on each individual conductor. When these conductors are pulled into a pipe, two or three "skid" wires are wound in a spiral around each cable on top of the shielding tape, and provide the return path for the carrier. Table II - 11 presents attenuation figures for different types of pipe cable.

Table II - 11

Approximate Attenuation of Pipe-Type Cable
dB Per Mile
PHASE-TO-GROUND COUPLING

TYPE OF CONDUCTOR	Frequency kHz				
	40	50	60	70	80
138KV, 1250 MCM 1 Copper Skid Wire	3.2	3.55	3.85	4.2	4.4
138KV, 1250 MCM 2 Copper Skid Wires	2.48	2.88	3.35	3.75	4.15
345KV, 2000 MCM No Skid Wires	2.0	2.5	2.95	3.4	3.8

(2) Characteristic Impedance

The characteristic impedance of power cables is very low, typically between 25 and 50 ohms. Because of the low impedance, carrier channel bandwidth obtainable with conventional coupling facilities is highly selective compared to that on overhead lines.

(3) Line Noise

As noted earlier, power cable conductors are not susceptible to the same noise problems experienced on overhead power lines. Generally, the noise level is so low that carrier-receiver gain is not limited beyond that determined by the inherent noise in the receiver itself.

c. Insulated Shield Wires (ISW)

Insulated shield or static wires are steel or copper wires associated with high voltage transmission lines. The shield wires are strung above the power-carrying conductors and are positioned to "shield" the transmission line from lightning. The main advantage to be gained in using ISW for communications is the greater overall bandwidth that can be realized than can be economically provided over phase conductors with available coupling equipment. Before the advent of ISW, it was not practical to use frequencies between 12 and 50kHz because of the physical size of the coupling capacitor and line trap inductance required to couple these frequencies to the line, and the inherent high cost of these components.

(1) Attenuation

Steel shield wires exhibit the highest attenuation factor of all shield wire types, typically in excess of 1.0dB per mile at 100kHz. At the other end of the spectrum, copper exhibits an attenuation of 0.1dB per mile at the same frequency. The high attenuation of steel makes it impractical to use on long lines, but staisfactory communications can result over short line sections.

In general, aluminum clad steel conductors and copper shield wires have the lowest attenuation factors and therefore provide the most usable communications medium for both long and short line sections.

Figure II - 40 presents typical attenuation of steel and copper static wires over the frequency range of 100 - 300kHz.

(2) Characteristic Impedance

The characteristic impedance of an insulated shield

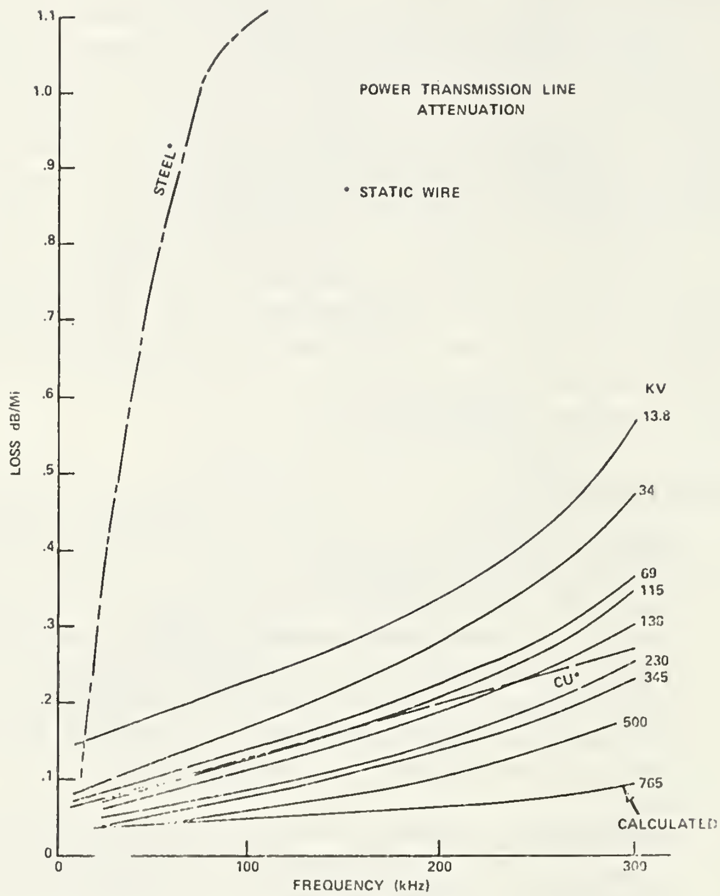


Figure II - 40 Approximate Attenuation for Static Wires

wire system is contingent upon the coupling equipment and the line tuning unit. In fact, depending upon how the "so-called" characteristic impedance is measured, or calculated, it will be reflected by the isolation of the coupling equipment from the line and/or the tuning unit from the carrier transmission equipment. Therefore, in any PLC/ISW system, one must deal with two characteristic impedances, the equipment side, and the line side. The equipment side impedance is nominally 50 ohms, whereas the line side is nominally 500 ohms for a single circuit and 900 ohms for a double circuit.

(3) Line Noise

Insulated shield wires exhibit high levels of line noise at the low end of the frequency spectrum. The lowest frequencies (10-20Hz) exhibit the highest noise levels, typically -10 to -25dBm at 10Hz to 25kHz to -37dBm at 20Hz. Therefore, the lowest frequencies should be used on the shortest line section, where the attenuation will offset the high noise value to provide an acceptable signal-to-noise ratio.

d. Coaxial Cable

Coaxial cables consist of either a solid or stranded wire inner conductor surrounded by a polyethylene dielectric. Copper braid is woven over the dielectric to form the outer conductor , and a waterproof vinyl covering is placed on top of the braid. This cable is made in a number of different diameters. It is moderately flexible, and is easily installed.

In power line carrier work, coaxial cable is not used as the transmission mechanism per se. Instead, the cable is used to interface the carrier equipment with the coupling equipment.

(1) Attenuation

For the lengths of coaxial cable used to connect the carrier equipment to the line tuning units, the losses are very low. Therefore, practically all of the transmitter power will be applied to the power line or static wire.

Typical losses in coaxial cable as a function of frequency, when the cable is properly terminated

is shown in Table II - 12 .

Table II - 12

Approximate Attenuation of Coaxial Cable
dB per 1000 Ft.

Frequency, kHz	Loss
20	0.20
50	0.44
100	0.55
150	0.66
300	0.90

(2) Characteristic Impedance

When installing power line carrier equipment, it is necessary to match the characteristic impedance of the transmission line to the impedance of the coaxial cable used between the carrier equipment and the line tuning unit. An impedance matching transformer is provided in the tuning unit for this purpose.

Typical values of characteristic impedance for different coaxial cables used in PLC applications vary between 50 and 70 ohms.

(3) Line Noise

Since the coaxial cable used in PLC is not a transmission medium, it is not susceptible to line noise as are the other cables in this section. Any noise associated with coaxial cable in PLC applications would be due to external interferences, and as such is not covered in this bulletin.

2. Noise and Interference

Noise and interference as unwanted disturbance within a useful portion of the frequency band, arise from many different sources. Power Line Carrier and Insulated Static Wire facilities are vulnerable to interference from other carrier signals and from noise. The noise level at the input to a carrier receiver determines the minimum received signal level necessary for satisfactory performance. This is commonly known as the Signal-to-Noise Ratio (SNR). Interference from other carrier services can be prevented by careful coordination of frequency assignments, and the use of line traps. Additionally, certain conditions such as parallel line sections and switchyard cross coupling should be avoided because of the potential interchange of energy between lines that could result.

Several of the significant noise sources and their corresponding characteristics are discussed below. However, it should be pointed out that line noise consisting of discreet pulses, occurring either erratically or periodically, superimposed on a random background noise at a lower level is one of the major, if not the paramount, cause of degraded performance in carrier systems.

Random noise is associated with transient disturbances, random in nature, with a Gaussian spectral distribution similar to thermal noise (White Noise). It is recognizable as a background "hissing" sound in telephone circuits. Random noise can be caused by thermal agitation in the power line conductors, and by pick-up of atmospheric static.

Impulse Noise manifests itself by non-overlapping transient disturbances. Low level amplitude discharges, at a large number of different points, although individually discreet pulses, together, may add up as random noise. Impulse noise causes an irregular "frying" or "crackling" sound, or a "buzz", if the impulses occur periodically. Impulse Noise can be caused by lightning strikes, switching, and line faults that produce impulses at a random rate.

Corona discharges cause modulation of the noise voltage envelope by superimposing additional noise impulses in cadence with the positive peaks of the power frequency voltage. The effects of Corona discharges can be minimized by use of "bundled" conductors and special hardware on extra high voltage (EHV) lines to hold Corona losses within reasonable limits and to keep radio interference fields in the vicinity of power lines to tolerable levels. The result of the Corona discharge is to

alter the impedance of the power line such that signals are absorbed at a varying rate. This produces amplitude modulation of the carrier signal on the line. The modulated carrier is in the form of a group of high-peaked noise spikes at the positive and negative peaks of the 60 Hz voltage of all three phases. Increased transmitter power, or reduced attenuation, will therefore not improve the signal-to-noise ratio in this case of Corona Modulation. Additional transmitter power, or less attenuation, does help reduce the effect of additive noise produced by Corona.

Thunderstorms produce discharges which are picked up by the line and are reflected in noise levels as high as 10 times the fair weather value. Light rain after a period of dry weather increases the noise level. The first moisture deposited on a dusty insulator will increase the conductivity and the leakage considerably. After the rain has washed the dust off, the noise falls, but not to as low a value as during fair weather. On EHV lines, noise increases considerably with snow or rain, but attenuation changes very little.

The level of noise appearing on a transmission line is influenced by the operating voltage of the line. Line noise increases and decreases, as does the line operating voltage. The interference effects of noise have different interference effects on different kinds of carrier receivers for the same location. Various methods of measuring and describing noise voltages are used in the attempt to relate these values properly. Because of the complex nature of power line noise, methods have been developed for performance of the above stated functions, some of these definitions are:

- Peak Value - refers to the maximum amplitude of repetitive noise impulses that will affect a trigger circuit, as is found in electronic switching devices. (i.e.-automatic simplex carrier telephone circuits)

- Average Value - represents the area under the amplitude-time curve, divided by the appropriate time interval and is that value that will affect the detector d.c. output circuit for telegraphic functions such as protective relaying, telemetering, or other services associated with keyed carrier facilities

- RMS Value - is an effective voltage representative of noise power. RMS values can be used to relate a noise value within one bandwidth to a value that may be expected within another bandwidth

- Quasi-peak Value - is related to the peak value and to the impulse repetition rate. It is based on a measuring circuit having fast charge and slow discharge time constants. It is a measure of the masking effect of the noise as a background for speech. Listening tests have shown that Quasi-peak values more closely relate to time nuisance values of noise in telephone circuits

Most noise measuring instruments are designed to measure average values. Therefore, they are of limited value in determining the speech masking effect (Quasi-peak) or interference with electronic switching devices (peak). At the present time, no consistent ratio between various values of noise exists, making it impossible to predict the peak or quasi-peak value from a measurement of the average. Average and peak noise values can be measured using a signal generator in a substitution technique, but no single substitution method has yet been devised to measure quasi-peak values. Some minimum recommended carrier signal-to-noise ratios for various applications are given in Table II - 13.

In narrow band receivers such as those used for frequency shift telemetering, differences in the interfering effects of various types of noises are less discernable. Average values of noise due to interference on protective relaying, telemetering, or other services, when applied on keyed carrier facilities, are more representative than other measures of noise.

Noise levels depend upon the voltage, dimensions, degree of contamination, and other conditions of a power line. They may vary over a wide range with changes in weather conditions. Practical methods whereby an accurate prediction of noise on a given voltage and type of line can be made leave much to be desired at present. Determination of actual ranges of noise, should be obtained via continuous measurements and recordings during all types of weather conditions.

TABLE II - 13
Minimum Signal-To-Noise Ratio

Keyed Carrier Telemetering	Carrier Relaying Or Supervisory Control	Tone Telemetering	Voice Communication
15 dB	20 dB	15dB for a single received tone, ($15 + 20 \log_{10} N$) dB for multiple tones, where N is the number of tones	15dB minimum on automatic simplex systems. 10dB tolerance for short periods on other systems. 20dB good, 30dB excellent

Since the power-line noise is dependent on the following:

1. Conductor Size
2. Corona Discharge
3. Line Faults
4. Weather
5. Voltage

it is not feasible to reduce the noise level at a receiving point in a carrier system; the only practical way to improve the SNR is to raise the signal level at the receiving point. It is usually not feasible to raise received signal levels by increasing transmitter power because appreciable gains require large increases in power. A more practical solution is to reduce channel attenuation through judicious application of line traps, to eliminate short taps on spur lines and alternate paths.

3. Attenuation and Carrier Frequency Response

As a result of the very wide variation in the size of power line facilities and their associated transmission media, carrier channel attenuation has been found to vary considerably with each system's: transmission conductor size, conductor spacing, height of conductors above the ground, line distances, ground resistivity, and the frequency used in the communication system.

Typical values of attenuation for low voltage lines (46 - 69 kV) vary from 0.13 dB/mile at 50kHz to 0.45 dB/mile at 200 kHz. These figures result since low voltage lines

have smaller conductors, which, in turn, have higher resistance, and thus, higher attenuation. Higher voltage lines (300 to 500KV) have larger conductors, and therefore lower resistance and resulting attenuation. Typical values for these lines vary from 0.3 dB/mile at 50 kHz to 0.5 dB/mile at 200 kHz. Intermediate lines (110 to 220KV) exhibit values of attenuation from 0.5 dB/mile at 50 kHz to 0.14 dB/mile at 200 kHz.

Transmission lines in the 300 - 500 KV range usually consist of bundled conductors, and when their spacing distance is greater than their height above the ground, the line attenuation varies with the spacing used, and the ground resistivity. Considering similar lines spaced identically, typical values of attenuation run from 0.25 dB/mile to 0.13 dB/mile at 50 kHz; 0.3 dB/mile to 0.23 dB/mile at 100 kHz; and 0.5 dB/mile to 0.44 dB/mile at 200kHz.

4. Channel Bandwidth

Every communication signal, whether it be one or more voice channels, a telephone signal, or a train of data pulses, or finally, a band of frequencies necessary to insure the transmission of information at the rate, and with the quality required under certain specified conditions, occupies a certain finite bandwidth in the communication systems frequency spectrum. The greater the information content of the signal, the greater the bandwidth required to accommodate it. The bandwidth required for voice transmission is determined by speech characteristics. Most speech energy, as a result of its characteristics, is concentrated and transmitted in the lower frequencies, while the higher frequencies contribute mostly to the transmission of intelligence or data. Thus, each voice grade channel must include the ability to transmit both the lower and higher frequencies.

In PLC communications, each voice channel utilizes a bandwidth of 4kHz. Approximately 300 Hz of this bandwidth must be reserved for guard bands at the edge of each channel to provide isolation from adjacent channels. This function reduces the useful bandwidth of the channel 300 Hz to 3700 Hz. Typically, a 3600Hz tone is used for telephone signaling and the filter roll-off characteristics use up an additional 300Hz thereby further reducing the individual 4kHz voice channel to a useable bandwidth of from 300 to 3400Hz, or 3.1 kHz. These factors considered, the communications system engineer must

in the systems engineering and design phases, assure himself that he has made maximum use of the individual channel and total system bandwidth available to him in the communications equipment that has been selected for installation within the system.

5. Frequency Allocation and Bandwidth

To fully utilize the total frequency spectrum allocated for any communications system, total consideration and adequate, practical utilization must be given to the frequency allocated for the system, and also to the mode of modulation selected for the system. The prefered method of modulation for PLC systems at this stage in their development is Single Side Band (SSB)

Using this technique, the particular number of PLC and ISW Channels is only limited to the interference criteria adopted by the borrower. In practice, the driving criteria will be the performance of those priority channels such as allocated to protective relaying, supervisory control, and data acquisition.

The theorectical frequency range for use for PLC and ISW systems may be from 8 kHz to 300 kHz. It is anticipated that future systems may extend into the 400kHz region.

The specific number of one-way or two-way circuits to be provided is determined in conjunction with the overall planning as outlined in Section II - B.

In the utilization of the frequency spectrum, it is noted that each 4kHz channel can accommodate a voice signal, a voice signal plus 6 tones above the voice channel (voice plus), 18 tones alone, or two transfer-trip line-relaying signals and a voice channel. It should be remembered that even though the bandwidth of each channel is 4 kHz, the practical bandwidth, as previously stated, is reduced to 3.1 kHz in actual application. Figure II-41 illustrates how this 300 - 3400 Hz channel can be used for single wideband functions such as telephony, relaying, or data, or how, with the use of speech-plus filters, voice frequencies above the 2200Hz level can be cut-off so that speech frequencies above this cut-off point can be used for other functions simultaneously with speech.

In assigning these 4kHz channels, the following "rules-of-thumb" are suggested when frequency allocations are to be made: 1. The lowest frequency should be used for the longest line section, 2. A frequency group on

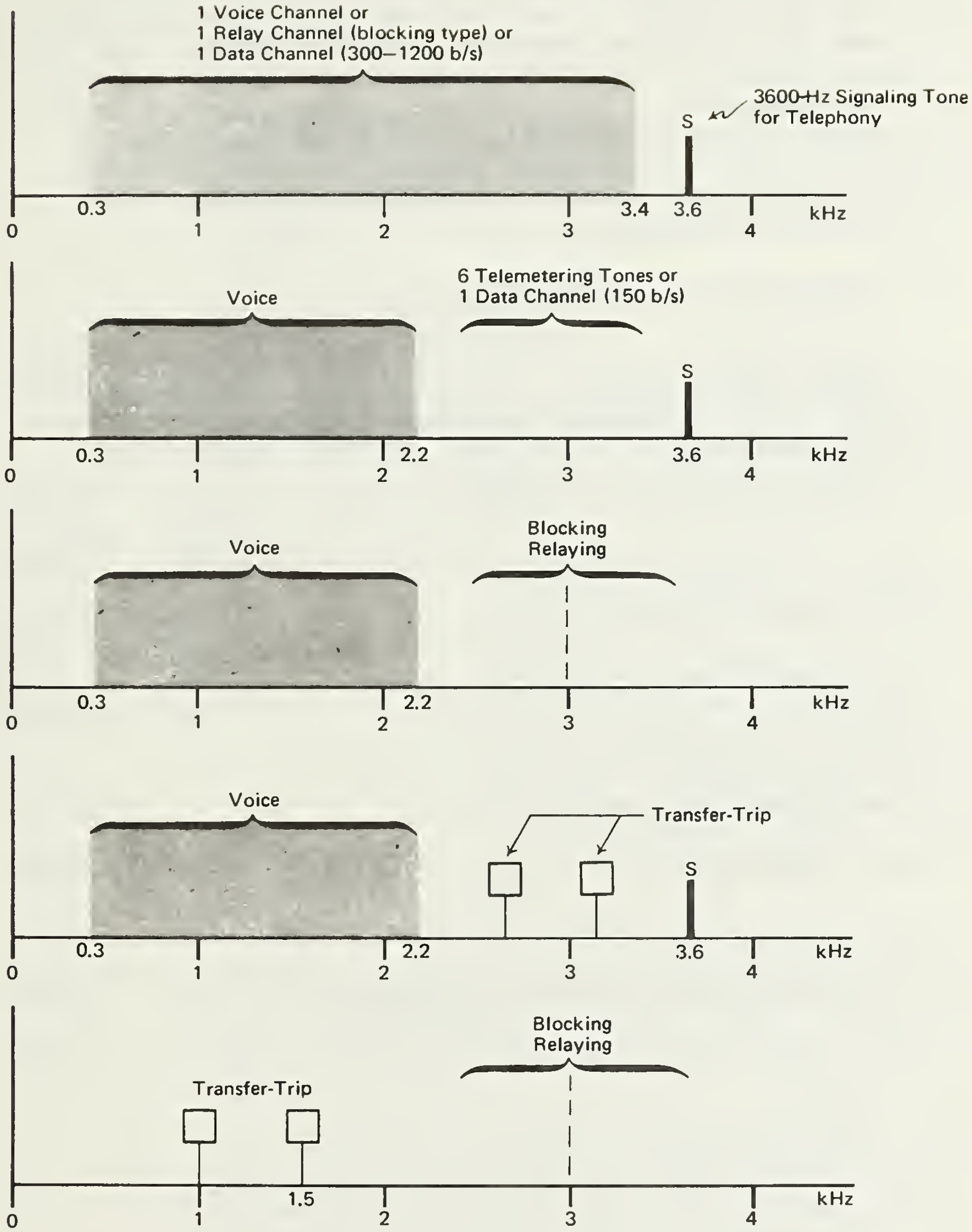


Figure II - 41 Voice Channel Function Allocations

connecting power line sections of the same voltage should utilize a repeat pattern of 2 line sections and 3 busses, 3. A frequency group on connecting power line sections of different voltages should utilize a repeat pattern of 1 line lection and 2 busses, 4. Use frequency groups between 48 - 228kHz as frequently as possible for construction economy, 5. Frequencies can be re-used more often than indicated in 2 and 3 above by trapping all phase wires, and by using coupling capacitors on the buss to ground each phase wire. This will result in a system that yields good isolation between non-parallel lines out of any substation.

6. Voice Frequency Transmission Levels

Voice frequency circuits associated with PLC and ISW may extend from a switching center, or from a telephone exchange to the channeling equipment. Either 2-wire or 4-wire terminations can be used. Typical input-output audio levels are as follows:

	2-wire term.	4-wire term.
Min. voice input level for full modulation	0dBm	-16dBm
Max. voice output level	+3dBm	+10dBm
Min. tone input level (speech-plus) each tone *	-2dBm	-10dBm
Max. tone output level(speech-plus) each tone *		-20dBm
Min. tone input level (tone only)	----	-20dBm
Max. tone output level (tone only)	----	-20dBm
Min. tone input level (data channel)	----	-20dBm
Max. tone output level (data channel)	----	0dBm

* NOTES:

1. Tone ports are 4-wire
2. Audio characteristics are for non-compandored channels
3. Tone levels given are for each tone
4. Tone levels are for standard adjustments using six tones above voice for speech-plus, and 10 tones for tone only operation

7. Channel Capacity

Earlier in this bulletin the nominal bandwidth of a voice channel was stated to be 4kHz. Figure II - 41 Section II F 5, illustrates how the 4kHz channel can be used for single wideband functions such as telephony, relaying, or data. By reducing the voice bandwidth to 2200Hz, and using speech-plus filters, it is possible to transmit tones above voice in the same channel for low speed data (300 and 600 baud). For high speed data the reduced bandwidth is inadequate. However, by increasing the bandwidth to 3kHz, data at speeds of 1200 and 2400 baud can be accommodated.

8. Input-Output Impedances

The specifications of input and output impedances is necessary to insure that when systems or equipment are interconnected, operation will be normal. Interconnection of two unmatched impedances will usually result in undesireable effects such as:

- Inefficient transfer of energy from one piece of equipment (or system) to another
- Reflected energy flowing in a direction opposite to normal flow
- Active devices such as transistors, operating into loads different from the normal loads which were considered in the equipment design, in turn resulting in increased distortion or overloading.

A mismatch between a transmission line and the input impedance of the equipment at the receiving end of the line will result in standing waves and a greater line loss than would occur if there were an impedance match at that point.

A typical impedance is composed of a resistive component and a reactive component. In special cases, either component can be zero. When two equal impedances are connected together, there will be no reflection of energy at the junction, and a maximum transfer of energy from one impedance to the other.

If two impedances,

$$Z_1 = R_1 + JX_1$$

$$Z_2 = R_2 + JX_2$$

are matched, the following relations must exist:

$$R_1 = R_2 \quad \text{and}$$

$$X_1 = X_2$$

When an equipment input or output is connected to a transmission line there should be a match between the equipment impedance and the impedance of the transmission line.

9. Return Loss

It is unrealistic to expect a perfect match between two interconnected impedances when used over a range of frequencies, so it is necessary to specify the limits of permissable deviation from a perfect match. The parameters used to specify mismatch are Voltage Standing Wave Ratio (VSWR), reflection coefficient (P), and Return Loss (RL). VSWR is used for radio frequencies and return loss for audio frequencies.

The value of return loss in dB can be found from

$$RL\ (dB) = 20\log_{10} \left| \frac{Z_1 + Z_2}{Z_1 - Z_2} \right|$$

where Z_1 and Z_2 are the two impedances to be interconnected.

To illustrate the application of this equation, assume that a 10 watt transmitter, having an output impedance of 60 ohms is coupled to a high voltage transmission line by means of RG-8/U coaxial cable. The high voltage line has a characteristic impedance of 600 ohms and the coaxial cable has characteristic impedance of 50 ohms.

By connecting the coaxial cable to the output of the transmitter, a return loss of

$$RL\ (dB) = 20\log_{10} \frac{60 + 50}{60 - 50}$$

$$= 21dB$$

results. This is considered an excellent figure for return loss since if the impedances are matched so that $Z_1 = Z_2$, the equation shows that the return loss is infinite.

On the other hand, connecting the coaxial cable to the high voltage line results in a return loss of

$$RL\ (dB) = 20\log_{10} \left|\frac{50 + 600}{50 - 600}\right|$$

$$= 20\log_{10}\left|\frac{650}{550}\right|$$

$$= 1.5dB$$

The low figure return loss reflects the high degree of unbalance that exists between the cable impedance and line impedance. The greater the departure of the line impedance from its normal value, the more power is reflected back, and the smaller the return loss.

10. Drop Level Stability

Any variations in voice frequency levels that may occur in the channeling equipment at a terminal "drop" in a PLC/ISW circuit is referred to as Drop Level Stability. These variations in voice frequency levels may result from appreciable variations in the attenuation losses of the line sections between "drops", and must be promptly compensated for by equal variations in the carrier equipment. In practice, voice frequency signal levels can be maintained within $\pm$ 0.5dB by means of regulation techniques inherent in the carrier equipment.

11. Frequency Stability

Frequency stability is the ability of a transmitter or receiver to maintain an assigned frequency. This is extremely important in single sideband equipment since the change in voice frequency that occurs between the

transmit end and the receive end is very critical. If too much "drift" occurs, the voice frequencies will be rendered unintelligible to the ear. Modern SSB PLC equipment is designed to exhibit a high degree of frequency stability --- typically $\pm$ 1.5Hz. With this figure, the end-to-end frequency difference of a voice system will not exceed 3Hz which is considered to be a very good circuit.

12. Pilots

Pilots are usually single frequency auxiliary signals transmitted over a communication system for supervisory control, synchronization, sensing, and alarm functions. In power line carrier equipment, a pilot carrier frequency is sent to the remote receiver for automatic gain control (AGC) and frequency -lock purposes. Should the AGC output vary beyond preset limits, an alarm relay is activated. Frequency-lock pilots are used to maintain end-to-end frequency stability. This is extremely important in systems carrying telegraph and high-speed data. By synchronizing the carrier frequencies in one terminal with those at the distant end terminal, any frequency drift in one terminal will result in a similar drift at the other terminal.

Pilot frequency and number of pilots depend on the particular system and the frequency allocation and modulation plan in use. Pilots are gererally transmitted at a level 10 to 20 dB below the system test tone level.

G. Systems Performance Analysis

1. Amplitude Modulation

Amplitude Modulation (AM) is one of the oldest forms of modulation. The carrier used in many communications systems is a high frequency carrier having a sinusoidal wave of the form:

$$A \sin (2\pi F t + \theta)$$

where:

- A is the amplitude
- F is the carrier frequency
- t is the elemental unit of time
- θ is the phase

In amplitude modulation, the carrier frequency is held constant and it's amplitude is modulated by changing the amplitude in proportion to the amplitude of the modulating signal. The modulating signal may be voice, tone, etc.. The resulting modulated wave form consists of the carrier frequency with it's amplitude modified in direct relation to the amplitude of the modulating signal. Figure II - 42 is a diagram of the foregoing discussion. Thus if $B \cos 2\pi\mu t$ is the modulating signal where μ is the modulation frequency, the resultant amplitude-modulated carrier is given as:

$$a = A\,(1+m \cos 2\pi\mu t) \sin (2\pi F t + \theta)$$

where:

- a is the instantaneous value of the variable (current or voltage)
- m is the modulation factor (m x 100 percent is called percentage modulation)

The shape of the envelope is the same as that of the information to be transmitted. Figure II -42 shows that the resultant modulated signal contains not only the original carrier frequency, but also frequencies above and below the carrier frequency. These frequencies are referred to as sidebands and are located above and below the carrier at a distance equal to the frequency of the modulating wave. When the percent modulation is equal to 100%, the amplitude of the sideband in either side of f_c is equal to that of one-half of the carrier and the carrier power of each of the sidebands is one-fourth the power of that contained in the carrier. The total average power during

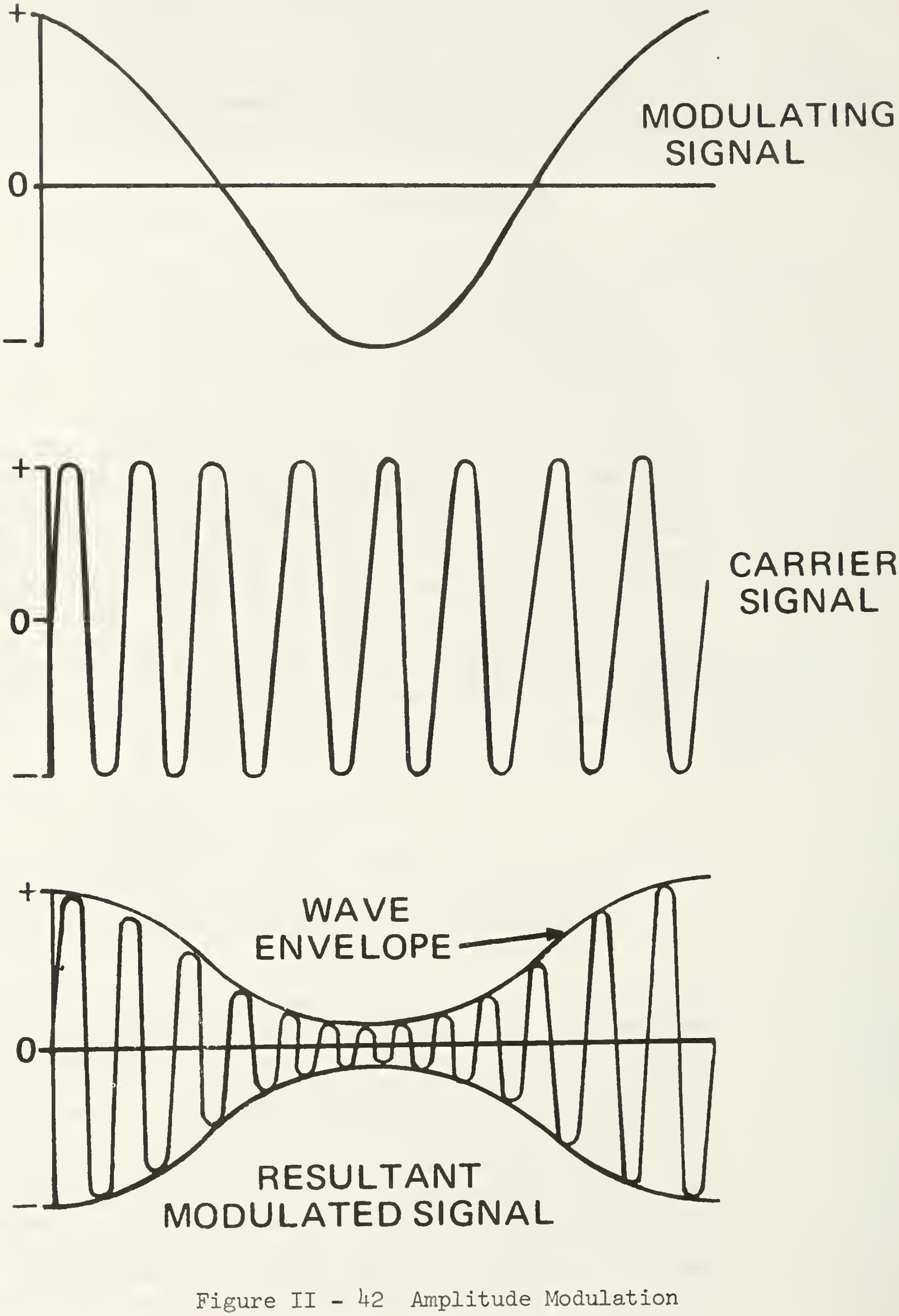


Figure II - 42 Amplitude Modulation

complete modulation is 1.5 times the unmodulated carrier power.

When a complex waveform such as speech is impressed upon a carrier, the sidebands have the same bandwidth as the carrier, and each sideband contains the same complex speed waveform.

The receiver must have a bandwidth sufficient to encompass the transmitted carrier plus its sidebands. The bandwidth required is equal to twice the frequency of the highest modulating signal transmitted.

This wide bandwidth associated with the receiver has its undesireable effects in that the wider the bandwidth, the more energy admitted into the receiver, both desireable, and undesireable. The undesireable elements may appear as noise such as that due to the amplitude effect of line noise, or cross coupled intelligent or unintelligent signals. Therefore, it is desireable to reduce the bandwidth of the receiver and at the same time still receive all the transmitted signal.

Single Sideband (SSB) accomplishes the bandwidth reduction desired and at the same time yields the desired information. SSB is a form of amplitude modulation, except that in transmitting, it transmits only one of the sidebands,either the upper or lower, since they both contain the same intelligence and this intelligence is also contained in the primary modulating carrier. Hence we now have a receiver that only has to be one-half as wide as that required for pure AM. In addition, we also suppress the carrier, thereby keeping the percentage modulations down, and reducing the effects of distortion. This so-called halving process produces an overall improvement of the noise performance, and conserves the frequency spectrum. Figure II - 43 illustrates some of the aspects of SSB-Suppressed Carrier (SC) transmission. Another advantage of SSB-SC is to reduce the susceptibility to Corona modulation, an undesireable interfering noise present in power systems communications.

2. <u>Frequency Modulation</u>

In Frequency Modulation (FM), the instantaneous frequency, F, given by:

$$a = A \sin (2\pi\ Ft + \theta)$$

is varied in accordance with the signal (speech, tone, etc.) to be transmitted. Stated somewhat differently, a carrier

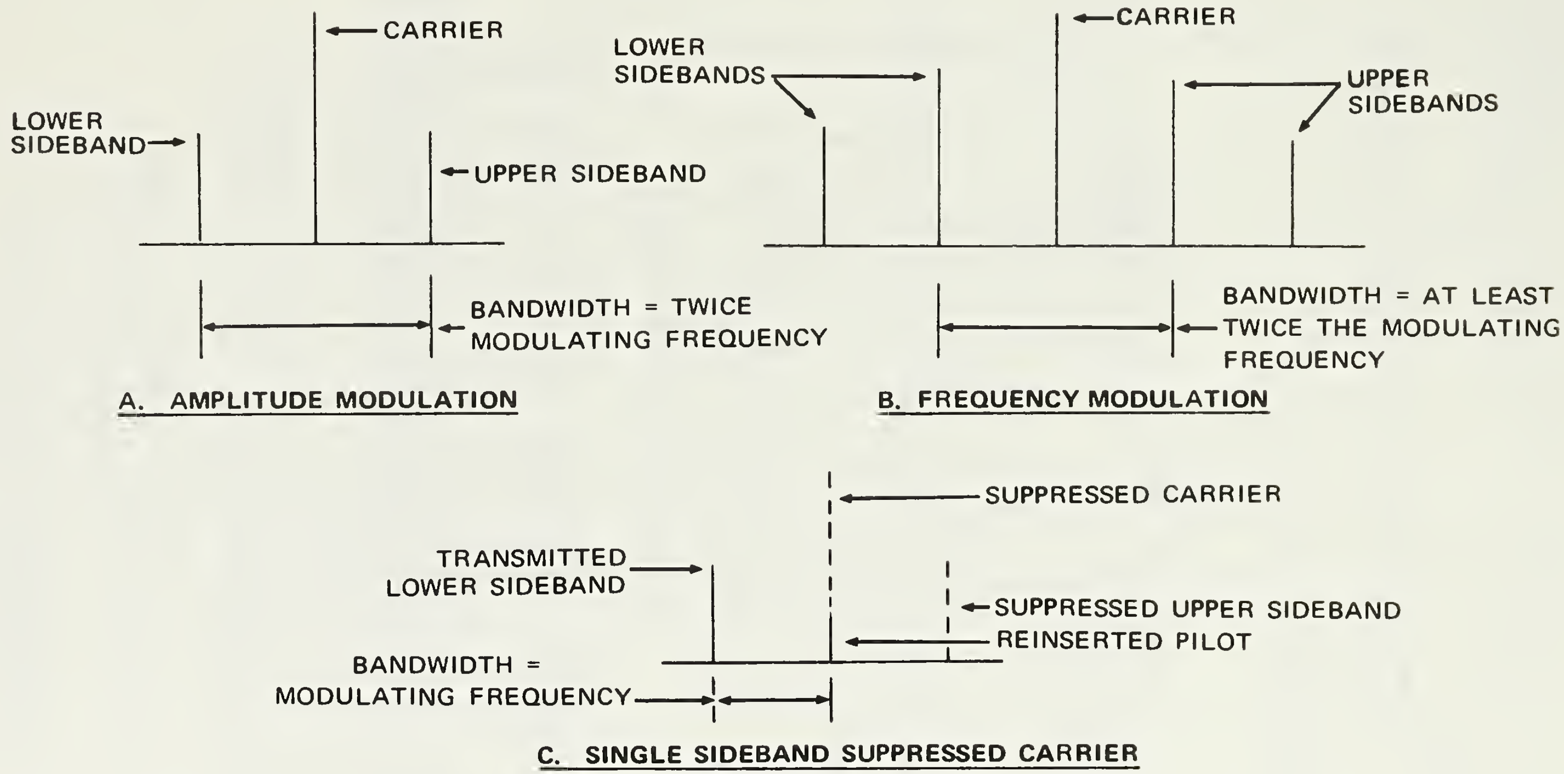


Figure II - 43 Bandwidth Comparison

signal is modulated by changing its frequency by an amount directly porportional to the amplitude of the modulating signal, and at the rate of the modulating frequency as shown in Figure II - 44. We define instantaneous frequency as:

$$\text{Instantaneous frequency} = \frac{1}{2\pi}\frac{d\theta}{dt} \quad \text{when:}$$

the frequency modulated signal is given by $a = A \sin \theta$, therefore if $\theta = 2\pi Ft$, then

$$\frac{1}{2\pi}\frac{d\theta}{dt} = F$$

The above keeps the definition of F commensurate with the expression given in II. G. 1. When the modulation (or the signal added) is $\cos 2\pi\mu t$.

$$\frac{1}{2\pi}\frac{d\theta}{dt} = F + \Delta F \cos 2\pi\mu t$$

where both F and ΔF are constants.

Integration yields:

$$\theta = 2\pi Ft + \Delta F \sin 2\pi\mu t + \theta_o$$

and the frequency modulated signal is;

$$a = A \sin \theta = A \sin \left[2\pi Ft + \sin 2\pi\mu t + \theta_o\right]$$

If both F and ΔF are large in comparision with the modulation frequency, μ, then the rate at which carrier cycles are completed will be $F + \Delta F \cos 2\pi\mu t$.

Unlike the sidebands contained in an amplitude modulated signal,a frequency modulated wave contains many sidebands, spaced equally above and below the carrier, assuming the modulation index exceeds unity significantly as is the case in normal practice.

The bandwidth required for an FM signal is given by Carson's rule which states that:

$$B = 2\ (\Delta F + 2f_m)$$

where:

B = FM bandwidth
ΔF = Peak carrier excursion
f_m = Top Modulating frequency

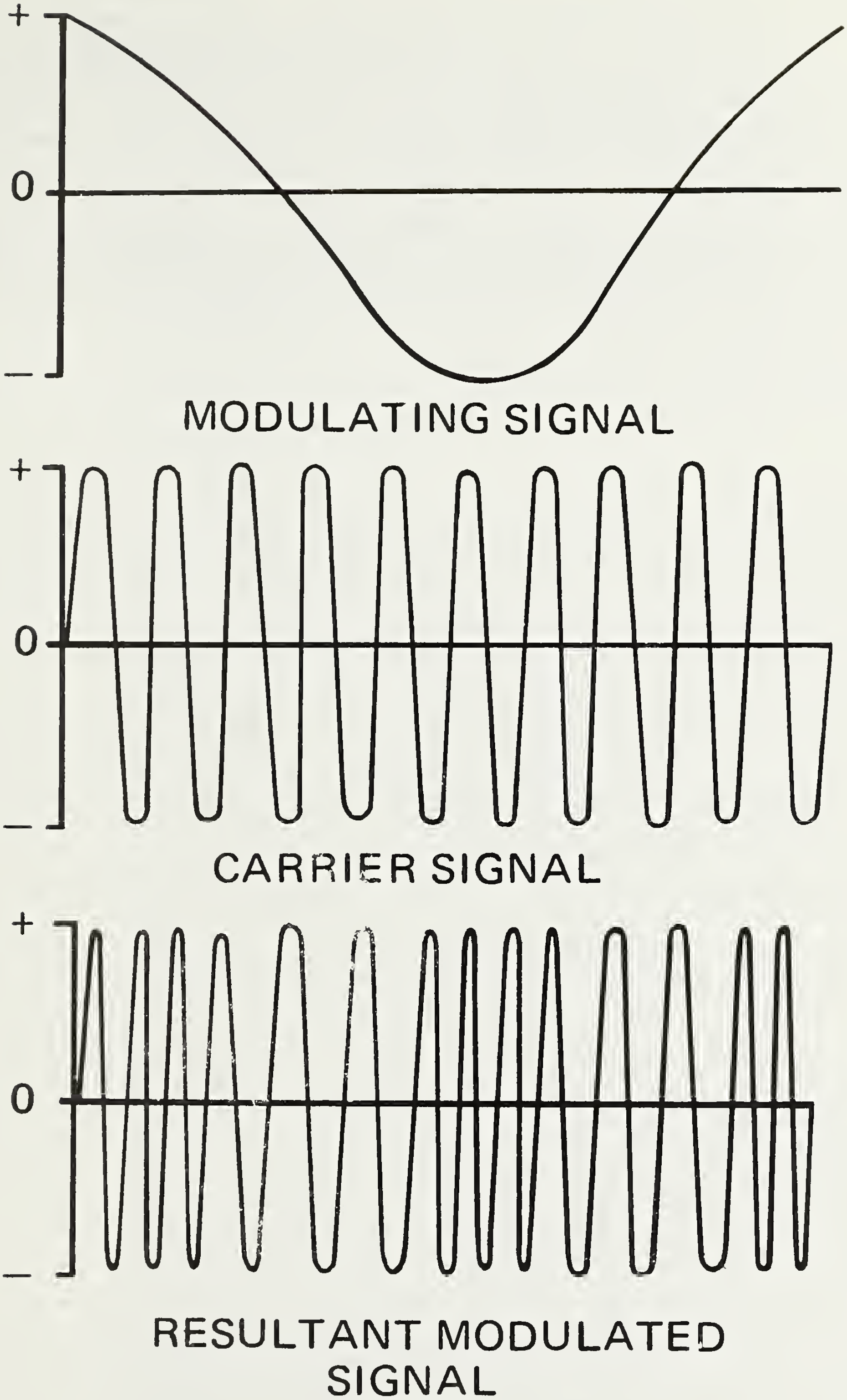


Figure II - 44 Frequency Modulation

as the modulation decreases below unity, the bandwidth approximates twice the modulating frequency. Certain assumptions are made regarding the filter characteristics, namely that that the filter is an n pole filter where n exceeds 3, and that 99% of the spectral energy is contained in the passband. The significant advantage in FM is that the signal-to-noise ratio in the derived channel increases as the modulation index increases. This is also limited by the amount of distortion introduced by overmodulation of the system. Also FM is not the most judicious selection when the frequency spectrum is at a premium.

3. Propagation

a. Modal Propagation

Several component theories have been developed to explain the concepts of the complex phenomena associated with wave propagation on the phase conductors of the power system. The natural mode concept is particularly helpful in predicting the distribution of carrier-frequency current among the power conductors and in explaining many apparently strange aspects of carrier behavior. A transmission line with n conductors has n current or voltage distribution among the n wires No mutual coupling exists between modes; all conductor impedances are equal for a given mode, and the attenuation to a carrier signal in each mode may be considered independently as a linear function of distance.

On a transposed line the three phases approach electrical symmetry for any basic configuration. A phase-to-phase carrier circuit on any two of the three phases, therefore, approaches balanced circuit behavior. On untransposed lines, e. g., single circuit with the three phases in the same horizontal plane, phase-to-phase carrier signals are balanced only when applied to the two outside conductors. The unbalanced wave propagated when a carrier signal is applied on adjacent phases may be perceived as having two components, one of which is the same as the previous balanced arrangement and another which involves all three phases. Despite the lack of symmetry, a carrier signal on adjacent phases has lower attenuation because the added three-phase component has less loss per unit of length of the line than the pure phase-to-phase component. However, a small additional loss is experienced at the receiving terminal because there is energy on the uncoupled phase which cannot be recovered.

Every carrier signal coupled phase-to-ground has both interphase components and a phase-to-ground component of carrier-frequency current flowing in the same direction in all three phases and returning through ground wires to earth. The attenuation per unit line length of this component is very high in comparison with those not directly involving ground currents, so that, within a short distance from a transmitter, the phase-to-ground component is essentially lost. This apparently fixed loss at the sending end is very significant if one is to obtain consistent estimates of phase-to-ground carrier attenuation. Energy on uncoupled phases which cannot be recovered at the receiving end of a line is also significant.

Because of electrical symmetry, phase-to-ground carrier on either phase of a transposed line will be propagated in a manner similar to that on the center phase of an untransposed line, because of different component distributions, it is attenuated more within a given line length than the previous examples.

The attenuation of a carrier current channel is defined as the ratio of the power supplied by the transmitter, terminated with its internal impedance, to the power measured at the receiver input. It is usually expressed in decibels, which is the log of this ratio. It has long been noted that in the propagation of carrier current signals, attenuation characteristics do not follow those associated with isolated two-conductor communication transmission lines. The theory of Modal Analysis has been applied to the multiconductor transmission system encountered in power systems. The Modal theory is founded on the principle that there will be as many modes of propagation as there are conductors in a system. Therefore, a simple, untransposed three-phase power circuit will have three natural modes of propagation.

Mode 3 has the lowest attenuation of all three modes. Mode 2 is slightly higher (approximately three times Mode 3) and Mode 1 has considerably higher attenuation (approximately 30 times Mode 3), because the signal must return through earth. Mode 2 attenuation is higher, in part, because the electrical field between the two conductors links the earth much more than the electrical field in Mode 3.

Regardless of how a carrier current circuit is coupled to a transmission line, either phase-to-ground, interphase or intercircuit, the signals ultimately adjust themselves to a combination of Modes 2 and 3. Mode 1 is attenuated so rapidly that it is of little consequence. In a transposed line, the natural modes are disturbed at each transposition and are constantly readjusting themselves and becoming disturbed by the next transposition; hence, the result is a composite propagation by Modes 2 and 3.

The technique used in the mathematical analysis of propagation of high-frequency signals on multiphase power lines is commonly called modal analysis. This name results because when a signal is applied on a multiphase transmission line it in effect breaks up into independent signals which are called modes. The name "modal signals" results from the mathematical techniques used in breaking the signal up into its modal or characteristic parts.

The analysis is similar to that used when analyzing an RLC network. The differential equation of an RLC network can be reduced to its characteristic equation which completely defines the "modes" of oscillation.

On first exposure, the modal theory of analysis may appear to be mathematical fiction, with very little relationship to the physics of real life. The precise relationship between the physics and the mathematics of the problem can most easily be demonstrated by a brief review of the basic results of the mathematical analysis. The solution is in matrix terminology and can be written as:

$$[V] = e^{-[\lambda e]} \times [V_o]$$

This solution is difficult to interpret because the term "e" to a matrix exponent does not have a simple physical interpretation in that form. Normally, a matrix equation can be thought of as a set of simultaneous equations, but the matrix exponent does not fit this form either. However, the above equation can be expanded into a matrix form which is more easily intrepreted. Complex matrix can be simplified substantially and is, for a three-phase line:

$$(V) = e^{-\lambda 1x} (e_1) + e^{-\lambda 2x} (e_2) + e^{-\lambda 3x} (e_3)$$

where e_1, e_2, and e_3 are the modal voltage matrices (vectors) which can occur on the transmission line, and the exponential terms are now complex, numbers rather than matrices. The exponents λ_1, λ_2, and λ_3 are the modal propagation constants.

The mathematical description of the problem does have a real physical interpretation which can be deduced from a closer examination of the equation. That is, any arbitrary voltage applied to the line will be broken into three modal voltages, with each mode having a distinct propagation constant. Generally speaking, the phase voltage equivalent of each of these three modal signals will have different propagation constants and each will propagate in a manner similar to the single phase wave on a single phase line. These modes of propagation are often called "natural" modes because they do occur physically on the line. The resultant voltage is the sum of these natural voltage waves on the line.

The problem of analysis of signal propagation on multiphase

transmission lines is difficult because of coupling between the phase wires of the transmission line. That is, when a signal is applied to one wire of the transmission line, a signal results on all the remaining wires. On the other hand, if a signal is coupled onto all three phases such that the relative magnitudes and phases of the applied signal are porportional to a mode voltage, no other modal quantities are produced on the line, i. e., if a signal of one mode is impressed on a transmission line, no other mode occurs as a result of this signal.

This concept can possibly be emphasized by comparing it with the symmetrical component concept normally used in 60Hz problems. If a positive-sequence voltage is applied to a transformer having balanced impedances, only positive-sequence current flows and no negative or zero-sequence voltages are generated. This is consistant with the argument that there is no coupling between the sequence networks. On the other hand, if the transformer with a tertiary winding had an unbalanced impedance, one would find that the application of a positive-sequence voltage would produce some circulating current in the tertiary. This is evidence that some zero-sequence current is flowing in the network. From this physical result we know that the sequence- network representation of the problem will require a coupling or connection between the sequence networks for the transformer. This is similar to the problem of intermode coupling in the carrier problem. As stated earlier, if only one mode is present on a uniform transmission line, no other modal voltages are generated.

At a discontinuity, however, even if only one mode arrives, other modes are generated; the generated modal voltages result from the arriving wave interacting with the discontinuity. Generally, in the case of carrier-current applications, there is intermode coupling at every major discontiniuty; i. e., at every carrier coupling terminal, every transposition, every transmission line configuration change, every line tap, etc..

A modal component network is shown in Figure II - 45. This figure is labeled as the refracted voltage diagram, and is the one most commonly used. Referring to Figure II - 45, the various portions of the modal component network will be discussed. First, the coupling capacitor and the transmitter in general will produce all three modal signals. The level of the signal in each mode will be equal to the transmitter voltage times the respective modal constants K_T1, K_T2, or K_T3. These constants must be calculated for the particular coupling and terminal

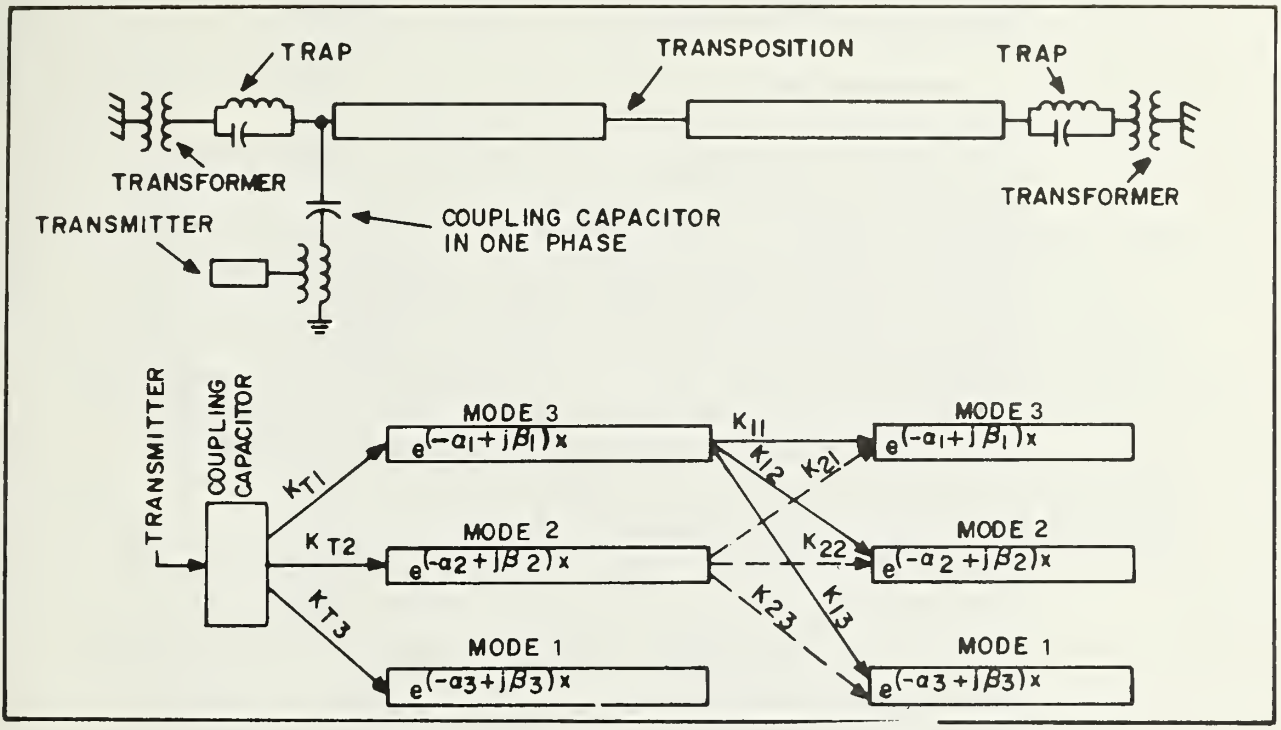


Figure II - 45 Refracted Modal Component Network

conditions. Thus, the resultant signal level in each mode is then determined. The signal level at the transposition or the end of the first line section is found by the product of the transmission characteristic and the input level. For example, the mode 1 signal is:

$$(\text{signal out}) = (\text{signal in}) \times e^{(-a_1 + j\beta_1) x} \quad (3)$$

From this it is observed that the mode 1 signal will be attenuated as determined by $a_1 x$ and the phase of the signal will be shifted as determined by $\beta_1 x$. At the transposition there is an interconnection between the networks. As shown, the signal arriving from the mode 1 network produces signals in all three networks of the leaving line. Correspondingly, the arriving signal in the mode 2 network produces signals in all three networks of the leaving line. The diagram shows no coupling from the mode 3 network because the high attenuation of the ground mode generally results in no signal arriving in the mode 3 network.

The concept described above has been used to describe in a general manner the effect of transpositions on long EHV transmission lines. In the past, simple examples have been used to demonstrate that each transposition produces a 6dB loss in the signal. This will result when the distance between transpositions and the attenuation factors are such that only the mode 1 signal arrives at the transposition. Another way of stating this is to say that both mode 2 and mode 3 voltages are attenuated to a negligible level between transpositions. For this condition of transposition, the mode 1 signal will transform energy into mode 1, mode 2, and mode 3. It can be easily shown that, in general, half the mode 1 voltage will be lost to mode 2 and mode 3 when passing through the transposition, resulting in 6dB loss of power. Then, if in the next transmission section both mode 2 and mode 3 are totally lost through attenuation, we would have a 6dB loss of energy through the transposition compared to the case with no transposition. In most typical applications, the above conditions are not met and the general rule of 6dB loss through a transposition cannot be used. In particular, if transpositions are close together there is little loss through each transposition.

The phase distribution and vector relationship of the three modes are shown in Figure II -46 and Table II -14 . These quantities are normalized to the phase A quantities. The factors p and q depend on the line under study. The factor p can range from about -1.6 to -1.9, and q will have a range of about 1.1 to 1.3.

The attenuation constant is given for frequencies of 30kHz and 300kHz. The attenuation can be expected to vary in a linear fashion between these two frequencies. The phase constant is given in terms of propagation velocity with respect to Mode 3, which is nearly the speed of light in free space.

These general ranges can by used to calculate line attenuation keeping in mind that the modal quantities add vectorally to produce the phase quantities.

When a carrier transmitter is coupled to the power line, it is usually done using single phase-to-ground or a form of phase-to-phase coupling. All of the generally used methods of coupling generate different portions of Modes 1, 2, and 3 power. Since Mode 3 is the least attenuated, then it is desirable to generate as much mode 3 as possible.

At the coupling terminal the phase voltages and currents are set by the coupling configuration and are known. The mode voltages generated must satisfy these boundary conditions and can be calculated by solving the set of equations shown below.

$$V_a = V_{a(1)} + V_{a(2)} + V_{a\,(3)}$$

$$V_b = +q V_{a\,(1)} + p V_{a\,(3)}$$

$$V_c = V_{a\,(1)} - V_{a\,(2)} + V_{a\,(3)}$$

If currents are used, then I is substituted for V in the above.

When the magnitudes for $V_{a\,(1)}$, $V_{a\,(2)}$, and $V_{a\,(3)}$ are calculated then the modal power at the transmitter can be found. P_T is equal to the total transmitter power less the losses in the coupling equipment.

$$P_T = P_{(1)} + P_{(2)} + P_{(3)}$$

where $P_{(1)}$, $P_{(2)}$, and $P_{(3)}$ are the modes 1, 2, and 3 powers respectively.

$$P_{(1)} = \frac{(1+q^2+1)\, V_a^2\,(1)}{Z_{o\,(1)}}$$

$$P_{(2)} = \frac{2V_a^2\ (2)}{Z_o\ (2)}$$

$$P_{(3)} = \frac{(1+p^2+1)\ V_a^2\ (3)}{Z_o\ (3)}$$

Now that the modal powers are shown, the modal coupling can be calculated

$$\eta\ (1) = \frac{P\ (1)}{P_T}$$

$$\eta\ (2) = \frac{P\ (2)}{P_T}$$

$$\eta\ (3) = \underline{P\ (3)}$$

where $\eta(1)$, $\eta(2)$, $\eta(3)$ are the modal coupling efficiencies. It is desirable to make $\eta(3)$ as close to unity as possible and $\eta(2)$ and $\eta(1)$ as close to zero as possible. The dB of transmitter power lost to Mode 2 and 1 is

$$\alpha_{(3)} = 10\log_{10} \eta(3) \quad \text{(dB)}.$$

	MODE 3	MODE 2	MODE 1
PHASE A	$\longrightarrow$ 1	$\longrightarrow$ 1	$\longrightarrow$ 1
PHASE B	$\longleftarrow$ p		$\longrightarrow$ q
PHASE C	$\longrightarrow$ 1	$\longleftarrow$ -1	$\longrightarrow$ 1

Figure II - 46 Mode Distribution

Table II - 14

Results of Modal Analysis			
PHASE	MODE 3 $I_{A\ (3)}$ or $V_{A\ (3)}$	MODE 2 $I_{A\ (2)}$ or $V_{A\ (2)}$	MODE 1 $I_{A\ (1)}$ or $V_{A\ (1)}$
A	1	1	1
B	p	0	q
C	1	-1	1
z_o (m)	z_o (3)	z_o (2)	z_o (1)

As stated before, each mode has an independent propagation constant. Based on several experimenter's data taken for lines from 345KV to 765KV the general range for the values of α and β are shown in Table II - 15.

Table II - 15

	ATTENUATION, α in dB/Ml 30kHz	300kHz	RELATIVE PHASE VELOCITY TO MODE 3
MODE 3	.01-.03	.07-.09	1
MODE 2	.09-0.1	0.4-0.5	0.8-.98
MODE 1	1.5 to 3 at 100kHz		0.9

This loss may or may not be a real loss to the receiver depending on the line length. Table II -16 lists the values of α (3) as conversion losses for several common coupling methods. The table is based on the assumption that the line is sufficiently long that the power in Modes 1 and 2 is negligible compared to the power in Mode 3.

Table II - 16

Mode 3 Conversion
Single End Losses
(A long Line Is Assumed)*

Type of Coupling	Conversion Loss, dB
Mode 3	0
Center Phase-to-Ground	1.8
Center Phase-to-outer Phase (Conductors driven electrically out-of-phase)	1.2
Outer Phase-to-Ground	7.0
Outer Phase-to-Outer Phase (Conductors driven electrically in-phase)	4.8

*NOTE: The line is assumed to be sufficiently long so that the power in Modes 1 and 2 is negligible compared to the Mode 3 power.

b. <u>Carrier Propagation</u>

The propagation of electromagnetic energy is reviewed here briefly. Further details involving the application of wave propagation are covered in the section on modal analysis. The solution presented here is the classical treatment for a steady-state voltage and current at any point along a two-wire line. This solution is approximately valid for carrier propagation between two phase conductors of a transposed three-phase power line, because the transpositions tend to nullify the effect of the third conductor. The solution is further compounded by the assumption that the line is made up of an infinite number of resistors and inductors in series, and an infinite number of capacitors and resistors shunting the line at equally spaced points. The solution may be expressed as follows:

$$V_s = \frac{V_r + I_r Z_c}{2} \, \ell^{(\alpha + j\beta) x} + \frac{V_r - I_r Z_c}{2} \, \ell^{-(\alpha + j\beta) x}$$

and

$$I_s = \frac{I_r + \frac{V_r}{Z_c}}{2} \, \ell^{(\alpha + j\beta) x} + \frac{I_r - \frac{V_r}{Z_c}}{2} \, \ell^{-(\alpha + j\beta) x}$$

where:

V_s and I_s are the sending end voltage and current res-respectively

Z_c is the characteristic impedance as defined in section 2.F.8.

$\alpha + j\beta$ is the propagation constant as defined below

x is the distance from the receiving end in units commensurate with those used to define $\alpha + j\beta$

From the above, it is seen that when a voltage is applied to the sending end, the voltage at any point on the line actually consists of two voltages, a voltage from the sending end toward the receiving end,

and another from the receiving end toward the sending end. These are denoted as E^+ and E^- respectively. Their corresponding currents are I^+ and I^- respectively. The ratio of either voltage to its corresponding current, at any point on the line is equal to the characteristic impedance Z_c which is independent of line length, but is a function of the series resistance and inductance and shunt capacitance, and shunt capacitance of the line per unit of line length. The characteristic impedance is given as follows:

$$Z_c = \left(\frac{R + j\ \omega L}{G + j\ \omega C}\right)^{1/2}$$

where
R = resistance in ohms per unit length
L = inductance in henrys per unit length
G = shunt conductance in ohms per unit length
C = shunt capacitance in farads per unit length,
and $\omega = 2\ \pi f$ where f is the frequency in hertz

At carrier frequencies, $j\omega L$ and $j\omega C$ are so large by comparison to R and G, the characteristic impedance may be given as follows:

$$Z_c = \left(\frac{L}{C}\right)^{1/2}$$

The phase and magnitudes of the voltage and current change as they travel along a line (for a two-wire line). The propagation constant is then defined as:

$$\alpha + j\beta = [(R + j\omega L)\ (G + j\omega C)]^{1/2}$$

The real part of $\alpha + j\beta$ is an exponent that denotes the decrease in amplitudes of the forward and reverse voltages and currents as they appear at various points along the line. The imaginary part expresses the phase shift of the voltages and currents that results from the time required for the waves to travel from one point to another along the line.

If carrier energy is applied to a single conductor of a multi-conductor line, the propagation characteristics must be determined using the technique shown in Section II.G.3 - Modal Analysis. Analysis shows that several modes of energy propagation exist simultaneously.

4. Losses

a. Shunt Losses

Shunt losses may be contributed by any and all paths to ground which attenuate the carrier signal energy.

The shunt loss of a station bus is primarily due to the capacitance of the breaker and transformer bushings, and the capacitance of the bus insulators. The capacitance to ground of a bushing is approximately .0002μF, and about .00005μF for a bus insulator. These values are a function of line voltage. A station bus having six bushings and twenty bus insulators per phase would give impedances of approximately 2500 ohms at 30kHz, 750 ohms at 100kHz, and 400 ohms at 200kHz. In cases where the bus impedance is unknown, it is suggested that an impedance of 800 ohms be used below 100kHz, and 400-500 ohms above 100kHz. The shunt loss of a bus (with line traps) may be calculated from the equation:

$$\text{dB of Loss} = 10\log \frac{Z_1 + Z_2 + \text{Trap Imp.}}{Z_2 + \text{Trap Imp.}}$$

where: Z_1 = Impedance of desired load
Z_2 = Impedance of undesired load

b. By-Pass Losses

The shunt loss at a by-pass is different from that at a transmitting or receiving shunt loss due to the double effect of shunts from two different paths. Consequently, a by-pass has a double-shunt loading; assuming a zero impedance at the bus, and using line traps the shunt loss for a trapped by-pass is equal to:

$$10\log \frac{Z_1 + Z_2 + \frac{\text{Trap Imp.}}{2}}{Z_2 + \frac{\text{Trap Imp.}}{2}}$$

where: Z_1 and Z_2 are as given above

For an untrapped by-pass the loss is equal to:

$$10\log \frac{Z_1 + Z_2}{Z_2}$$

When a discontinuity exists close to the transmitting point, so that a large fraction of the reflected energy returns to the transmitter, the line does not present its characteristic impedance as a load to the transmitter and may, in fact, present an impedance that is highly reactive in nature. In such cases, it is necessary to compensate for the reactive portion of the line impedance by proper adjustment of the line tuner, and to match the resulting resistive component of the load, which may be higher or lower than the characteristic impedance, by adjustment of the taps of the impedance-matching transformer in the tuner. Although the losses in the short section of line up to the discontinuity are greater than if the line were properly terminated, the increase is not serious except in extreme cases, and the only major loss, if any, is that in the device causing the discontiniuty.

On the other hand, when the discontinuity exists at an intermediate point in a channel, sufficiently far from the transmitting point so that essentially the characteristic impedance of the line is presented to the transmitter, the loss in the line resulting from reflection at the discontinuity may be considerable.

It has been shown that the additional loss caused by such discontinuities can be represented by the following formulas:

for series discontinuity

$$dB = 20\log_{10} \frac{\sqrt{(2Z_c+Rd)^2+X_d{}^2}}{2Z_c}$$

for shunt discontinuity

$$dB = 20\log_{10} \frac{\sqrt{(Z_c+2R_d)^2+4X_d{}^2}}{2\sqrt{R_d{}^2+X_d{}^2}}$$

In both formulas,

R_d = resistive component of impedance of discontinuity

X_d = reactive component of impedance of discontinuity

Z_c = characteristic impedance of line

where: Z_1 and Z_2 are as defined before.

c. Impedance Mismatch-Shunt

The shunt loss contributed by an impedance mismatch of trapped lines is:

$$10\log \frac{Z_1 + Z_2}{2}$$

where; Z_1 = Line trap impedance toward receiver

Z_2 = Impedance of tap line

Each shunt loss along a line must be calculated and their total loss must be included in the overall line attenuation.

d. Reflection Effects

For a tapped line such as the one we have been talking about, the following reflection characteristics must be observed:

- Unterminated Lines: For unterminated lines (not terminated with carrier equipment operating on frequency under consideration, or a line terminating into a power transformer) the maximum out-of-phase reflected signal occurs when the line length is electrically equal to one quarter wavelength, or odd multiples thereof

- Shorted Lines: For shorted lines (where power line connects to an underground cable of low impedance), the maximum out-of-phase reflected signal occurs when the line is electrically equal to one-half wavelength, or multiples thereof

$$\text{Wavelength in Meters} = \frac{300}{\text{F in MHZ}}$$

With an untrapped line falling into either category listed above, the reflected energy will be out-of-phase with that traveling the main line, and can cause attenuation, or even complete cancellation of the through signal. To minimize this cancellation effect, line traps are placed in the tapped line in close

proximity to the main line.

The signal travelling out on the tapped line will be attenuated 10 to 15dB by the line trap. The amount of attenuation is dependent upon the trap impedance with respect to that of the main line. The higher the trap impedance, the greater the attenuation will be.
The reflected signal will undergo a similar attenuation while passing through the trap on its return to the main line. Therefore, the reflected signal will be attenuated by an amount equal to twice the attenuation of the trap, thereby minimizing its effect on the through signal.

When trapping a tapped line, the trap impedance should be as high as possible, therefore no attenuation curves for traps as a function of impedance are provided here.

e. <u>Impedance Mismatch-Series</u>

Losses due to series mismatch are experienced when an overhead line is connected to a power cable. In such applications, the loss at each junction may be calculated by the equation:

$$\text{dB Loss} = 20\log\left(\frac{Z_1 + Z_2}{2\sqrt{Z_1 \quad Z_2}}\right)$$

where; Z_1 = Impedance of overhead line
Z_2 = impedance of power cable

f. <u>Attenuation at Discontinuities</u>

The characteristic or surge impedance of a transmission line is the impedance as measured at the input terminals if the line has infinite length or if a finite length of the line is terminated in a resistive load equal in value to the characteristic impedance. When a relatively short length of line is terminated in a load different from its characteristic impedance, the input impedance will differ from the characteristic impedance both in magnitude and phase. At the point of improper termination, there is a reflection of the energy back toward the source with a resultant increase in attenuation. In addition to the reflection loss, there is a loss in the device causing the discontinuity.

5. Voice Channel Delay

Delay distortion results when one frequency component of a signal is delayed more than other frequency components of the same signal.

In the transmission of voice, delay distortion is considered unimportant, since the ear is insensitive to phase differences. Also, if a syllable, or in some cases, an entire word, is lost in normal conversation, the listener automatically fills in the missing portion and sentence continuity is maintained. This is not the case, however, in the transmission of data at any speed. The higher the bit rate of data to be transmitted, the more sensitive the data is to a given amount of delay distortion.

In the transmission of data at 1200 bps, using binary codes, the two tones typically involved are 1200 and 2200Hz. The intelligence is transmitted by shifting from one frequency to the other at a 600Hz shift rate, which creates a broad band of frequencies. Delay distortion results when one frequency suffers a greater delay from transmitter to receiver than does the other frequency in the signal. In the transmission of binary data, the 1200Hz tone and the 2200Hz tone have entirely different meanings and the two tones are always transmitted in a certain sequence, never simultaneously. The effect of delay distortion upon the data transmitted may best be explained by the following example:

> Assume a normal data signal is transmitted where the 1200Hz tone is transmitted first, followed by the 2200Hz tone (each tone transmitted for one millisecond). Further assume that the channel equipment involved delays the 2200Hz tone one millisecond longer than it does the 1200Hz tone. The result is that both tones arrive at the receiver at the same time; thus the received signal conveys no intelligence. Should the 2200Hz tone be delayed two milliseconds longer than the 1200Hz tone, the 2200Hz tone will arrive at the receiver first; thus a reversal in intelligence. It is evident that the transmitted data is useful only if no additional delays have been introduced. Therefore, it is extremely important that delay distortion in data transmission be held to an absolute minimum.

In the transmission of complex signals, such as the binary code data, the two frequencies will form a modulation envelope. Because of non-linear phase shift in the channel equipment, the two frequencies will travel from the transmitter to the receiver at different velocities. The result is delay distortion to the modulation envelope resulting in envelope delay due to non-linear phase shift. The amount of envelope delay is therefore dependent upon the rate of phase shift; i.e. the greater the rate of phase shift, the greater the envelope delay.

A typical communications channel has a minimum of absolute delay near the center of the channel. Envelope delay distortion may be minimized by making the absolute delay nearly constant across the frequency band of interest. This may be accomplished by use of a delay equalizer that adds more delay to the center of the channel than to the band edges. Thus, equalization of the channel delay is obtained at the expense of increased total absolute delay. The use of delay equalizers in channels for high-speed data is common practice in communication equipment today.

6. Non-Linearity/Intermodulation

High level signals applied to the transmission equipment cause amplitude or phase distortions in the communications channel. This is termed as intermodulation noise. The base band signal or the base band load on the system are affected by such factors as the total number of channels, signal level, data tone level and individual speed levels. Increasing the signal level will decrease the random noise and certain types of impulse noise, but it will also increase the intermodulation distortion. Intermodulation distortion is determined by measurement in both PLC and ISW: optimization is then effected if required and a compromise is made. It is generally advisable to apply data tone at -8dBm0 or less, and a -16dBm test tone or less when setting up the voice channel.

7. Bandwidth Effects

The compensation for degradation to performance as a result of bandwidth limitations due to coupling equipment, unrelated carriers, and the inherent characteristics, are handled somewhat differently in design by the various PLC manufacturers.

While a frequency band from 200 to 6100Hz permits transmission of speech without loss of fidelity, this range is seldom employed in practical voice communications systems.

With a peak signal-to-average noise ratio of 30dB, of word intelligibility (the percentage of a group of non-related words that can be recognized and understood after transmission over a communications channel) of greater than 95 percent can be obtained when a frequency band of 300 to 2200 Hz is used. This bandwidth affords even greater intelligibility when related words, such as those found in normal sentence structures, are used. If greater fidelity is required, such as the requirements of a commercial telephone channel, an expanded bandwidth of 300 to 3400Hz is used. Expansion beyond this bandwidth is normally reserved for high speed data channels and is not normally found on power line carrier, PLC voice communications systems.

While it is obvious that different functions require different bandwidths, the use of non-standard bandwidths on various PLC equipment tends to waste frequencies allocated to PLC because of varied width guard bands required to prevent cross talk between channels. In recent years, the PLC industry has tended to standardize single sideband channel bandwidth to 4kHz and vary the utilization of this channel to fit whatever purpose is required by the user. Thus, after subtraction of approximately 300Hz from each end of the channel, a 3400Hz band is available for data, voice, voice-plus, tone relaying, etc. The guard bands are standard and minimize the amount of spectrum not being used for active communication. Further, there is some tendency toward allocating all services into frequency slots which are multiples of 4kHz to provide for more orderly growth and easier frequency planning.

Bandwidth requirements for other types of PLC channels, such as telemetry, blocking relaying, transfer-trip, supervisory control, and low speed data transmission are varied, but generally require less bandwidth than voice. Successful 30ms transfer-trip operations can be carried out over a channel less than 250Hz in bandwidth; however, wider bandwidths are used when greater speeds are required. When guard bands are included, this channel becomes a 500Hz band now used in commercially available relaying equipment. Frequency shift carrier, used with supervisory control, teletype, etc., may have smaller bandwidth requirements.

Bandpass filters are required for isolation of unrelated carrier equipment when this equipment is connected (coupled) to the same phase wire. These filters can provide isolation of more than 30dB of frequencies which fall within the passband of any other filter connected to the

the same bus.

The effects of taps on the bandwith have been previously discussed.

8. Selectivity

One of the most important equipment characteristics is the selectivity of receivers and the method of achieving that selectivity. If the user has intimate knowledge of isolation between lines, or the dB attenuation across busses, frequencies can be used closer together than would normally be expected. Hence, some of the data is given in terms of dB isolation which permit the user to determine the required frequency spacing. This then allows the best overall and most efficient allocation scheme.

Table II - 17 provides selectivity data on equipments used for multi-channel transmission in the frequency range from 8 - 300 kHz.

Frequency Range (kHz)	8-48	48-100	100-300	48-300	48-300
Selectivity in kHz (from center of passband)					
0.5 dB Front end	±1.8	±1.7	±1.8	±3.7	±7.7
50 dB Front end					±12.3
60 dB Front end	±5.0	±4.0	±6.0	±8.0	
0.3 dB Channel		±1.7	±1.7	±1.6	±1.6
60 dB Channel		±2.4	±2.4	±2.4	±2.4
0.5 dB Overall		±1.7	±1.7	±3.7	±7.7
60 dB Overall		±2.4	±2.4	±2.4	±2.4

9. Characteristic Impedance

Impedance or surge impedance may be defined as the impedance of an infinitely long line, and is determined by the conductor size and spacing.

In order to achieve the best coupling efficiency, the carrier coupling equipment is adjusted to match this impedance, which is modified by the parallel effect of the station bus and the associated line trap impedance.

On overhead lines, the characteristic impedance varies with the number of conductors in the line, and the type of coupling utilized. Typical values of this impedance are given in Table II - 18, as a function of

the above-mentioned variables. However, care should be taken in applying these values for other than planning purposes. Specific formulas given elsewhere herein should be employed whenever discreet design is involved.

Table II - 18
Typical Surge Impedances for Overhead Power Lines

Type of Conductors	Phase-to-Phase Coupling	Phase-to-Ground Coupling
Single Conductor	650-800 ohms	350-500 ohms
Bundled Conductors (2 wires)	500-600 ohms	250-400 ohms
Bundled Conductors (4 wires)	420-500 ohms	200-350 ohms

Where signals are transmitted over high voltage cables, the characteristic impedance and attenuation of the cable must be known. Both of these values depart considerably from those of overhead lines. Since they depend on the type of cable to be used, they have to be determined by measurement in each specific case.

Normally, cables rated for higher voltages have the conductors of the individual phases sheathed in a conducting enclosure which is connected to ground so that direct coupling between a conductor and ground is readily possible. Only a few values have so far been published for characteristic impedance and attenuation. The characteristic impedance ranges between 25 and 50 ohms and the attenuation is about 10 times that of overhead lines.

10. Line Noise

Noise values for fair and adverse weather are provided in Section II. F. 1. together with other noise criteria discussed in Section II. F. 2.

The performance of any power line carrier system can be predicted by the signal-to-noise ratio (SNR) at the receiving end of each channel. Figure II - 47 illustrates the relationship, in a general way, between signal and noise. To provide an intelligible signal,

the signal at the transmit end (the left side) has to be strong enough to overcome the attenuation along the transmission line and arrive at the receiver sufficiently higher than the noise level. That is, it must have an adequate SNR. Generally, the line noise on a given line section operating at the same voltage level has the same noise strength along the entire line. In some specific cases, it is possible that a leaky insulator, faulty line, hardware or localized weather condition on a given line section in one area might cause more noise at that particular location on the line than some other location. If the high noise source is at the receiving end of the line, it would cause more difficulty than if it were at the transmitting end. Noise from a source at the transmitting end would diminish with propagation along the transmission line to the receiving point in the same manner that the signal diminishes due to attenuation. However, for the purpose of performance calculation, it is normally assumed that noise level is uniform throughout the line section.

The carrier signal level in Figure II - 47 Indicates a modest loss at both the sending and receiving ends due to tuning and coupling equipment. However, since both the signal and noise are attenuated by the same amount by the tuning and coupling equipment at the receiving end, the SNR is really established on the transmission line at the receive terminal and remains constant to the input terminals of the receiver.

Figure II - 48 shows the effect of frequency on noise and attenuation levels. The attenuation is given in dB per mile whereas the noise level is given as a level independent of mileage. Because attenuation increases and noise decreases with increased frequency, the lower frequencies are generally used on long lines, and the higher frequencies are used on short lines. Although the dB per mile may be high at the high frequencies, the total dB attenuation along short lines can be very nominal, and a high SNR can be enjoyed because the noise is much lower at the higher frequencies. In longer lines, the total attenuation is more significant and lower frequencies are more desirable.

Where total attenuation is a concern, the method of coupling signals to the power line can be an important factor. Propagation studies indicate that the most efficient means of coupling is Mode 3. A user should consider using Mode 3 coupling for the most critical

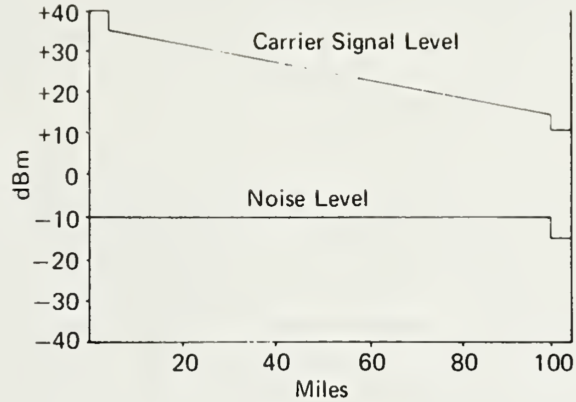


Figure II - 47 Noise & Signal Levels on EHV Lines

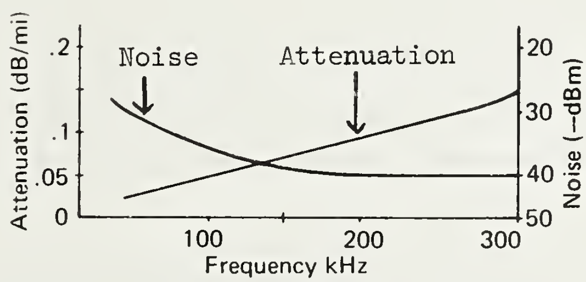


Figure II - 48 Typical Fair Weather Noise and Attenuation On 500 KV Lines

circuits in his system. He should also consider using Mode 3 coupling on very long EHV lines. Interphase coupling involving the center phase is the next most efficient type of coupling since a strong Mode 1 signal is produced here also. It is suggested that outer-phase-to-outer-phase coupling not be used. Center phase-to-ground coupling normally gives adequate performance, whereas outer phase-to-ground is not recommended except for short lines. Section II. G. 3 provides a more thorough discussion on modal theory.

The noise and received signal levels required for calculating the SNR can either be measured or estimated using data presented herein. The minimum SNR differs for different types of carrier equipment and functions being transmitted. Table II - 19 lists the minimum acceptable values. Since SNR is always expressed in decibels (dB), it is equivalent to the arithmetical dB difference between the received-signal level and the line-noise level.

Table II - 19

Minimum Tolerable SNR Values
According to Function

Function	SNR (dB) *
Voice/Multi-function	See Table II - 20
Impulse Telemetering (2.4 sec.)	0
6-27 Hz Telemetering	5
Data Rates	
60 Bits per sec (BPS)	5
300 BPS	10
1200 BPS	15
Phase Comparison Relaying	20
Directional Comparison Relaying	15
Transfer Trip - Single Channel	
25-30 ms	0
7 ms	5
4 ms	7
10 ms	8
10 ms	-3

* Based on noise measured in a 3 kHz Bandwidth (unweighted) across the 50 ohm coaxial cable input-output circuit.

For single sideband (SSB) systems, the calculation of SNR is slightly different than that for single-function carrier systems because the maximum available transmitter output power must be divided among various functions. Functions, which are intended for future additions must also be considered. A detailed description of this power division is contained under "Effective Transmitted Power" below.

In SSB channels, the receiver generally operates with higher sensitivity.

Table II - 20 gives the minimum values of acceptable SNR for voice and tone channels operating over SSB equipment.

Table II - 20

Minimum SNR For SSB Equipment

Type of Service or Function on SSB Channel	Minimum SNR*
Voice channel without compandor	30 dBm
Voice channel with compandor	15 dBm
Pilot or signaling tone	5 dBm
Tone channel for data, relaying, supervisory, etc.	15 dBm

* Based on noise measured in a 3 kHz bandwidth (unweighted) across the 50-ohm coaxial-cable input-output circuit.

11. Line Attenuation

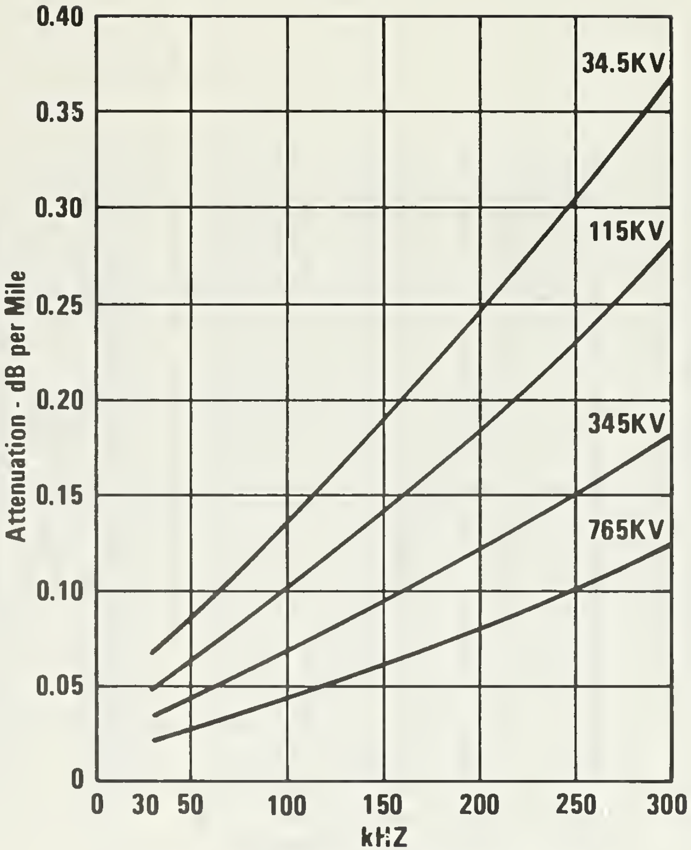
a. Overhead lines

Line attenuation depends upon several factors. Higher voltage lines usually have a lower loss, since the longer insulator strings effect lower carrier leakage and dielectric losses in the insulation. Figures II - 49 illustrates the typical fairweather losses for selected transmission lines. Corrections for adverse weather, transposition, and other losses are discussed elsewhere in this bulletin.

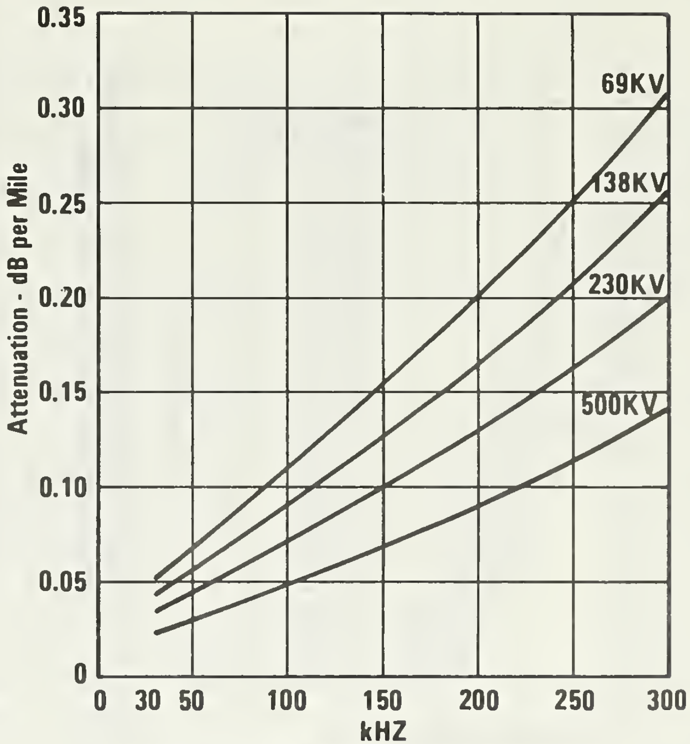
b. Power Cables

PLC is also used on power cables; especially in urban environments and near airports. However, the low surge impedance and high transmission losses of power cable limits its use to the 30 - 80 kHz region. The surge impedance of power cable ranges from about 20 to 40 ohms. Figure II - 50 shows both the impedance and attenuation ranges of power cable as a function of usuable frequency range.

c. Coaxial Cable



Typical Attenuation Curve For Power Lines
at 34.5, 115, 345, and 765KV



Typical Attenuation Curves For Power Lines
at 69, 138, 230, and 500KV

Figure II - 49 Line Attenuation vs Carrier Frequency For
Different System Voltages

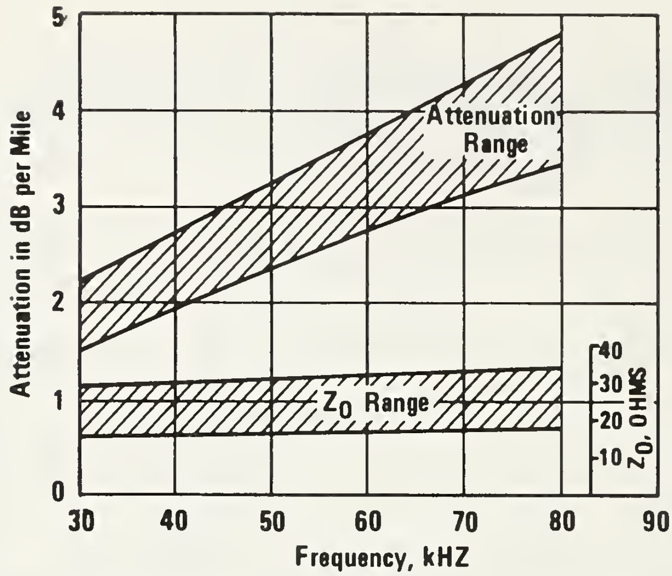


Figure II - 50 Phase-to-Ground Attenuation and Surge Impedance of 138 to 345KV Pipe-Type Power Cable

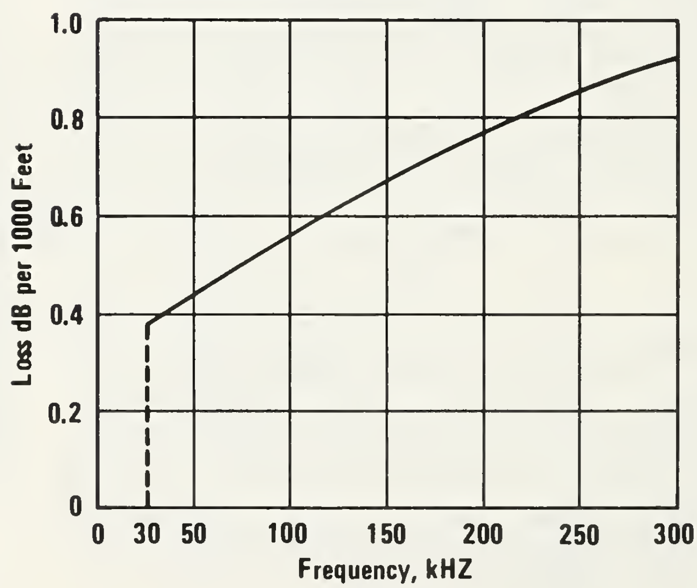


Figure II - 51 Attenuation of RG-8/U Coaxial Cable at Carrier Frequencies

Coaxial cable is used to connect the line tuner and carrier transmission equipment because of its low loss.

Figure II - 51 gives the attenuation of RG8/u coaxial cable; a frequently used cable. The attenuation ranges from about 0.4 to 0.9 dB/1000 feet over the 30 to 300 kHz frequency range.

12. Path Attenuation

The design of a power line carrier system requires careful consideration of several important factors. The calculation of attenuation is of great importance. The calculation of transmission-line attenuation at various carrier frequencies is dependent on several variables such as line voltage, line construction, method of coupling, weather conditions, and the absence or presence of ground wires. An examination of several studies on line attenuation reveals that the various investigators are not in complete agreement with each other as to the method of calculating line attenuation for phase-to-ground coupling as compared to phase-to-phase coupling. In some methods used, different attenuation values are utilized for phase-to-ground coupling than for phase-to-phase. Others determine line attenuation of phase-to-ground by adding a fixed additional amount to phase-to-phase attenuation. This additional fixed loss may vary from two (2) to six (6) dB. Modal analysis seems to verify that the latter approach is more logical, since carrier signals never actually propagate phase-to-ground, but resolve themselves into a modification of Mode 3. It is not sufficient to merely ascertain the attenuation of the high voltage line itself, but the design engineer must address the attenuation factors related to branch circuits, parallel paths, busses discontinuities, tuners, cable etc.. These factors have been discussed at length throughout this bulletin.

In summary the determination of path attenuation involves the following factors:

- Overhead line attenuation
- Attenuation due to mode of propagation used
- Effects of weather
- Power cables combined with overhead lines (as applicable)

- Cable entrance losses
- Fault attenuation
- Multipath losses
- Coupling losses
- Intermediate line taps
- Filter losses
- Bypass losses
- Shunt losses
- Shunt impedance losses
- Impedance mismatch losses
- Reflection effects
- Series impedance losses
- Equipment insertion losses
- Transposition losses
- Branch circuits

Subsequent to ascertaining the effects of the above system losses it is merely a matter of balancing gains and losses against the anticipated (calculated) noise level.

13. Carrier Coupling

Coupling losses may contribute a large part of the total loss. Equally important are the by-pass losses incurred at switching or sectionalizing stations. For the following discussion, phase-to-ground coupling is assumed, since this is most commonly used.

These losses, regardless of the type of coupling, are dependent upon the frequency, the coupling capacitor size, the line trap size, and the line impedance. Losses also occur in the tuning unit components and the coaxial cable.

a. Resonant Tuned Circuits

In a resonant single-frequency line tuner the factors most affecting the coupling losses are frequency, coupling capacitor size, and line (load) impedance. Single frequency resonant tuning units have higher losses at both the low and high frequencies. Losses range from approximately 0.5 to 4.5 dB.

Coupling losses of a two-frequency line tuner are dependent upon the same factors as those stated for the single-frequency unit. Two-frequency tuning units also have higher losses at the low and higher frequencies and range from slightly less than 2 dB to approximately 12 dB.

b. Wide-Band Tuned Circuits (bandpass tuners)

The bandpass tuner is an adjustable unit providing coupling capabilities for any band of frequencies between 30 and 300 kHz, with a minimum insertion loss. The amount of loss that may be expected is a function of coupling capacitor, frequency, and transmission line impedance. This loss is essentially constant over approximately 70% of the passband, centered around the geometric-mean frequency. Losses range from approximately 0.5 to 6 dB.

c. Coupling Capacitor Losses for Low Impedance Applications.

The carrier loss in coupling capacitors for overhead line applications is generally very small and can be neglected. For low impedance cable circuits the loss in the coupling capacitor can become very significant since the coupling capacitor resistive component at carrier frequency is comparable in magnitude to the cable impedance.

This loss can be calculated using the voltage divider principle in order to take this factor into account for each application.

Where cable and coupling capacitor impedances are equal, a 6.0 dB loss penalty will occur in each coupling capacitor, since only one half of the transmitter voltage is applied to the cable impedance. To keep the coupling loss relatively low, extra-high capacitors are usually required for the higher voltage power cable carrier applications.

Losses are very impedance sensitive and may exceed 18 dB in certain applications. The circumstances giving rise to this condition are usually recognized and avoided where possible.

14. <u>Channel Diagrams</u>

Figures II - 52 through II - 60 are application diagrams illustrating various channelization configurations and connectivity diagrams involving repeaters and telephone systems. Care should be observed in applying these configurations such that they are compliant with the overall frequency management of the system. Furthermore, it should be pointed out that different manufacturers may have slightly different equipment arrangements to satisfy the same requirement.

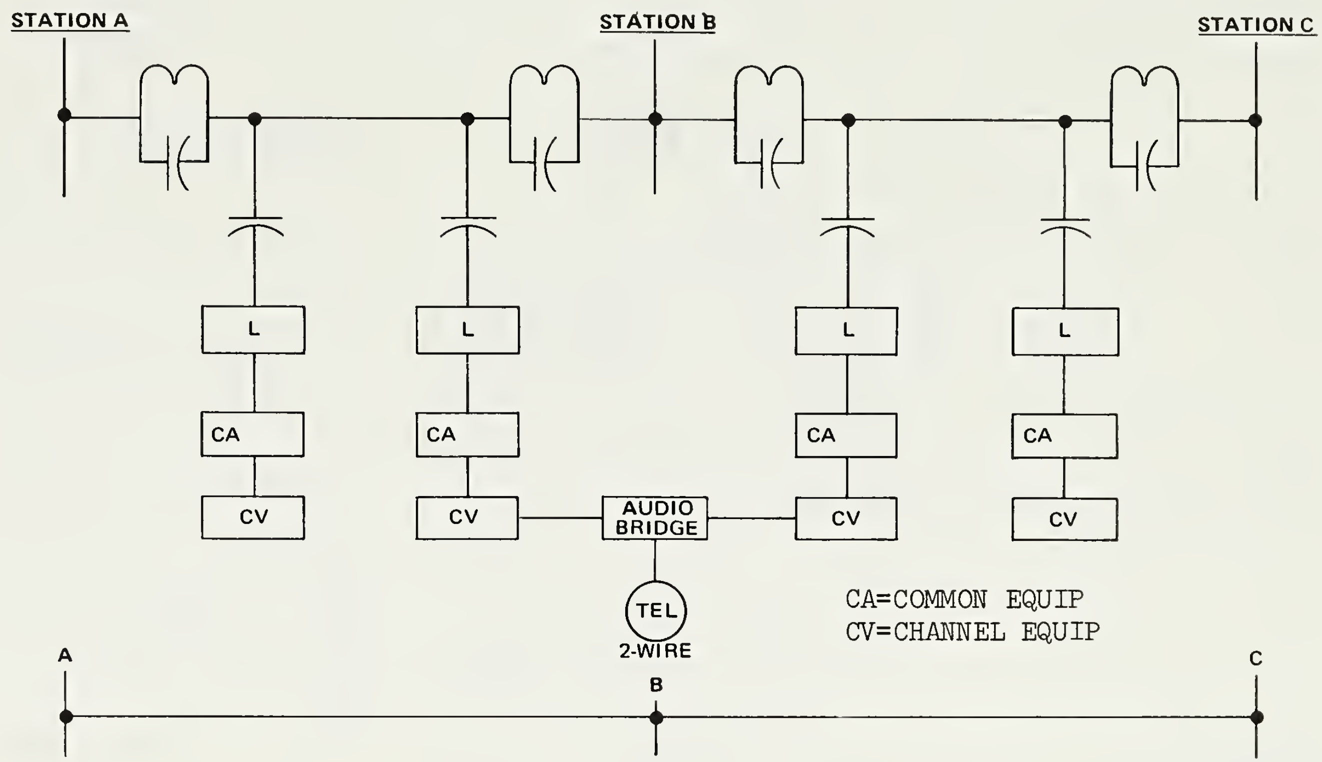


Figure II - 52 Single Voice Channel Using 2-Way Audio Repeater at Station B With Telephone Drop

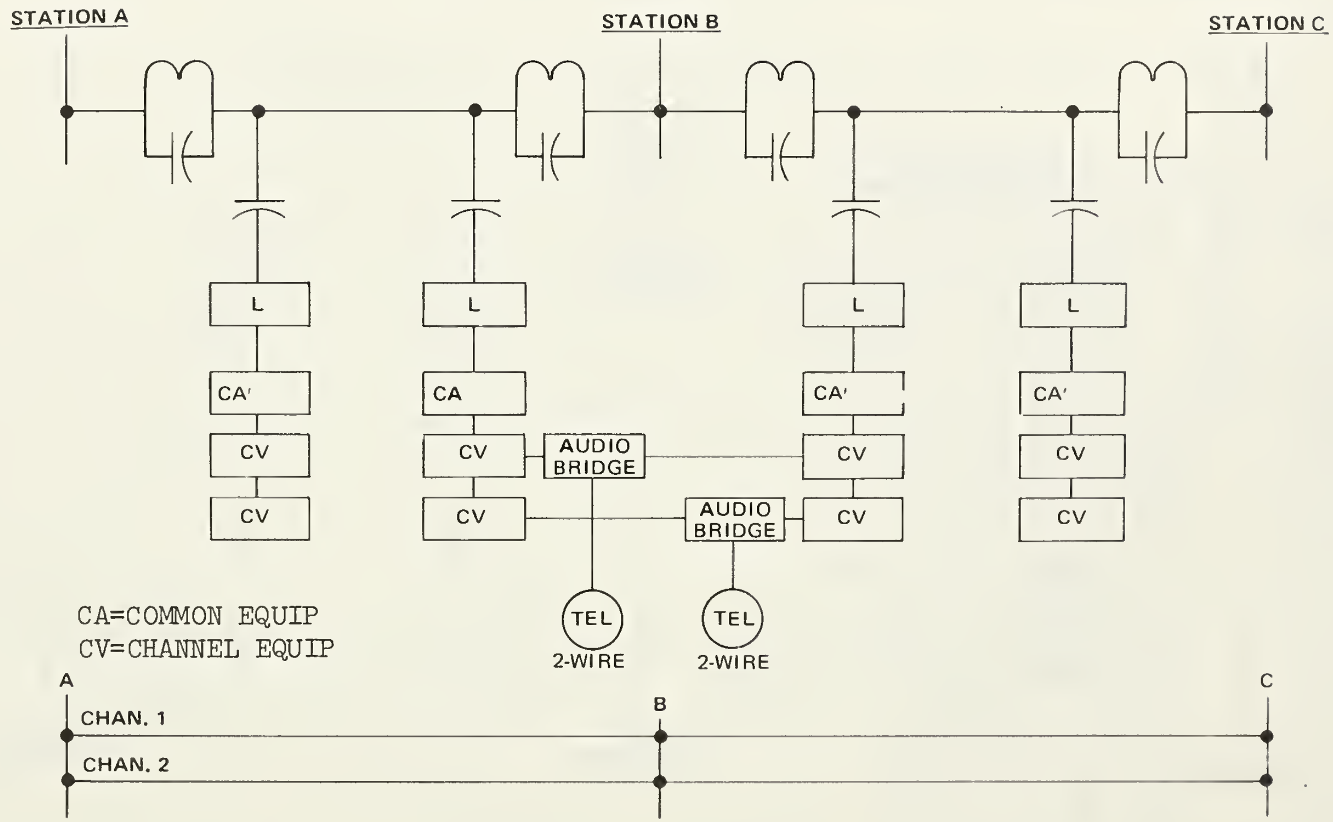


Figure II - 53 Two Voice Channels Using 2-Way Audio Repeater at Station B With Telephone Drop

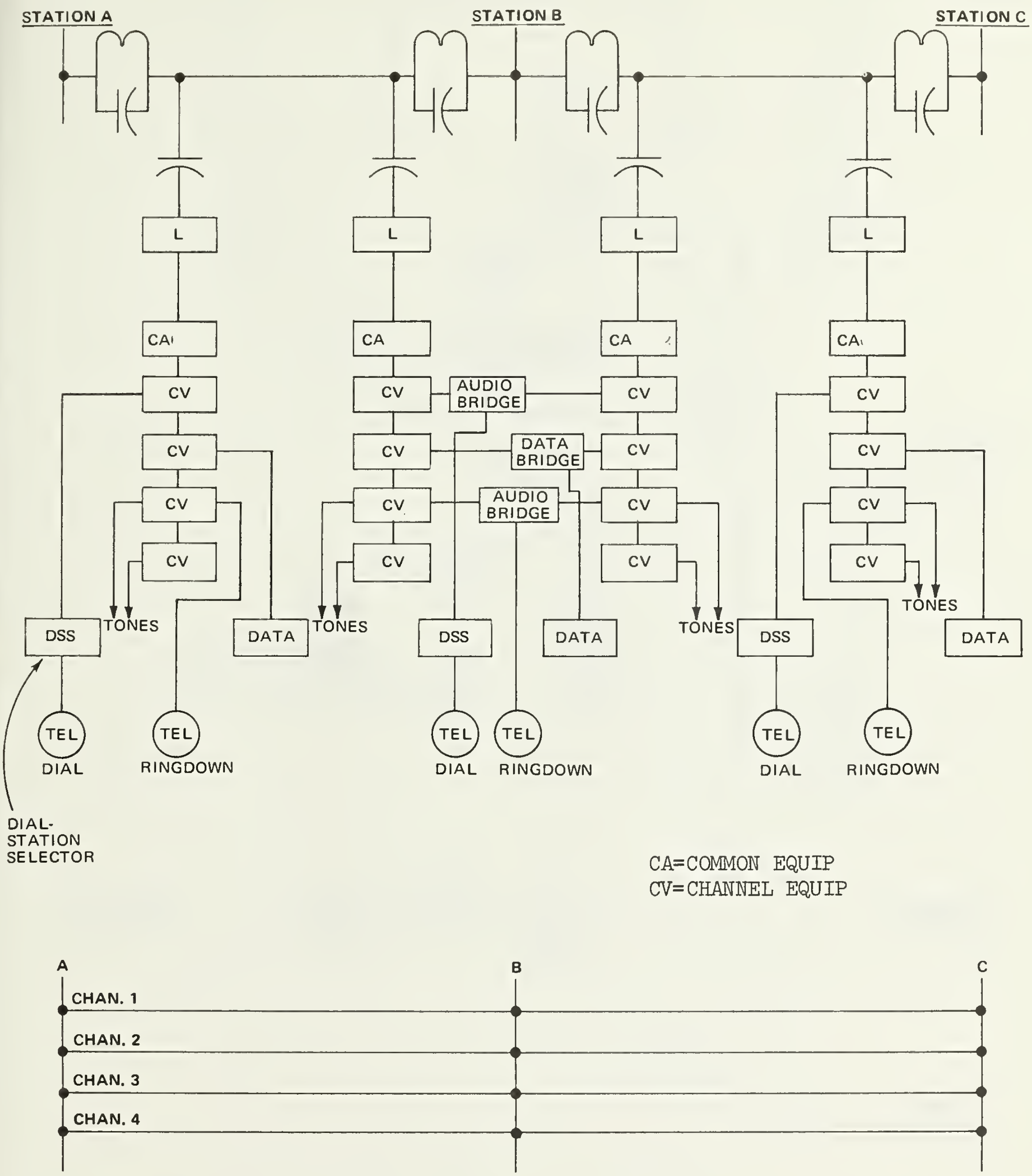


Figure II - 54 Combination of Data, Tone, Telemetering, and Voice Using Audio Bridges

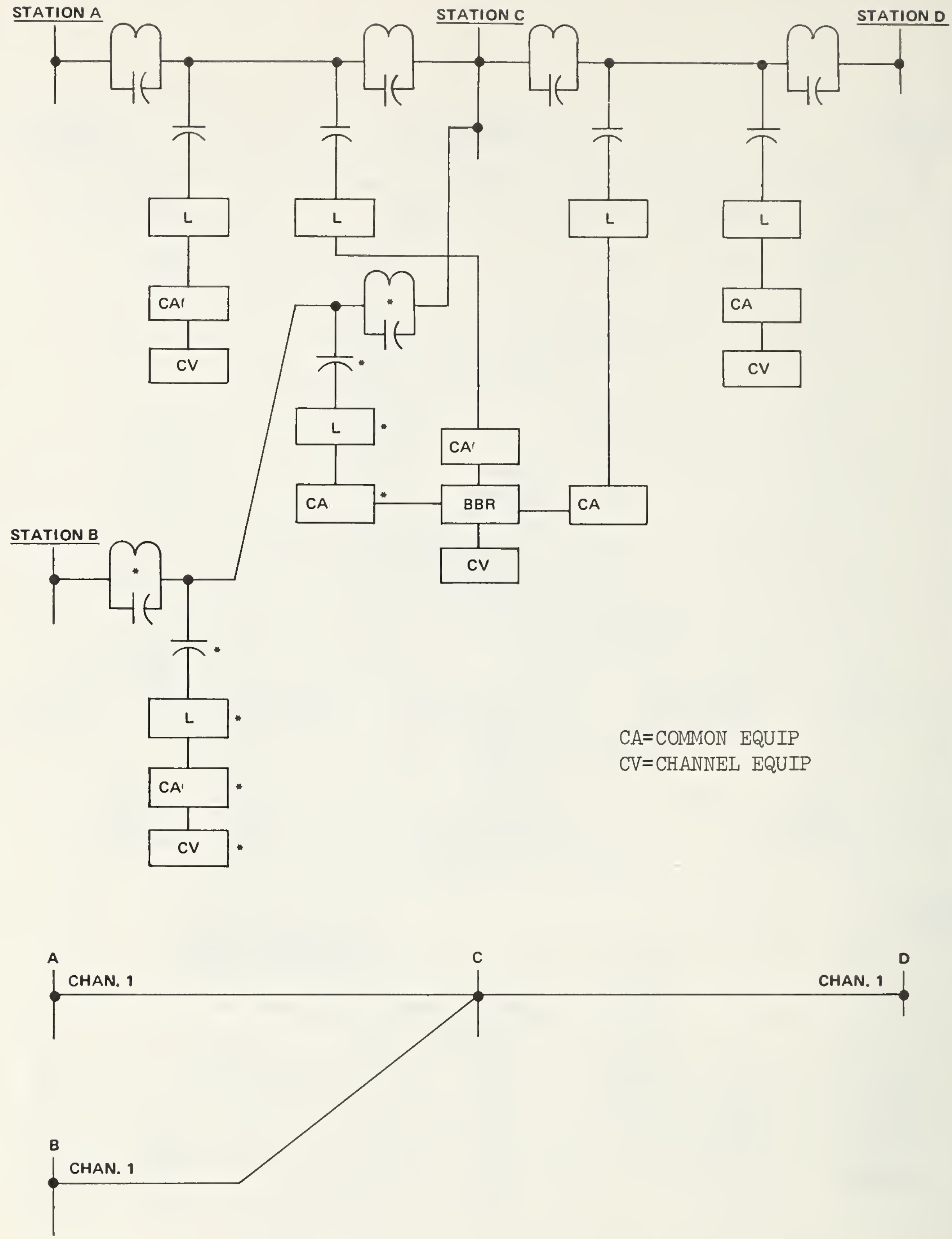


Figure II - 55 3-Way Baseband Repeater Using Single-Channel TErminal Equipment

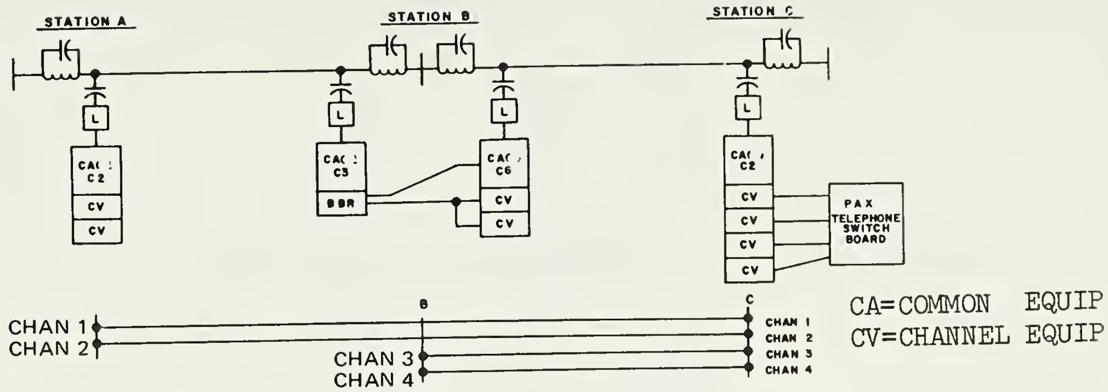


Figure II - 56 2-Way Baseband Repeater With 2 Remote Stations

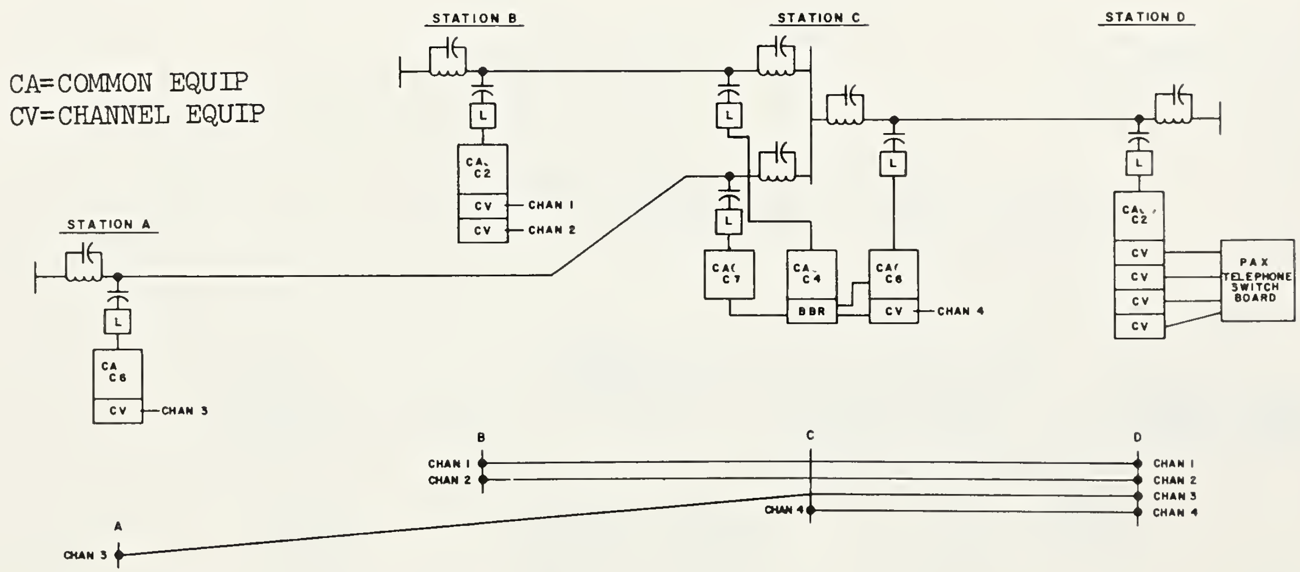


Figure II - 57 3-Way Baseband Repeater With 3 Remote Stations

CA=COMMON EQUIP
CV=CHANNEL EQUIP

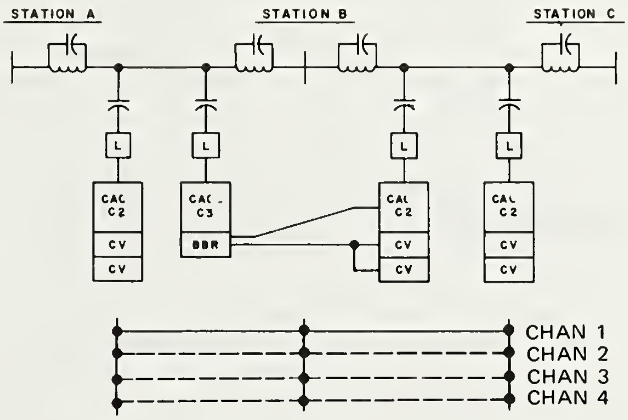


Figure II - 58 Party Line Telephone System Between 3 Stations With Baseband Repeater at Station B

CA=COMMON EQUIP
CV=CHANNEL EQUIP

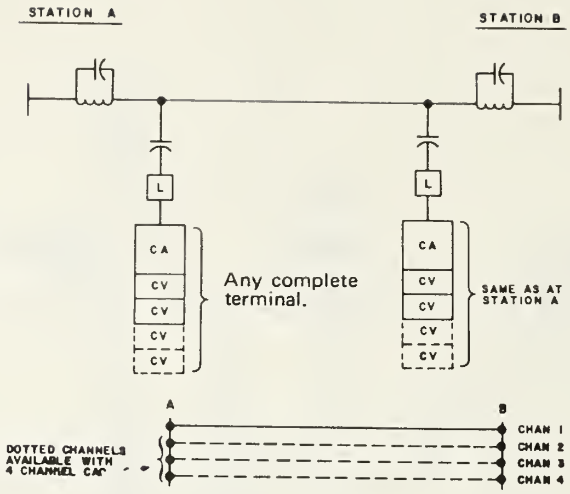


Figure II - 59 One to Four Simultaneous Voice Channels Between Two Stations

CA=COMMON EQUIP
CV=CHANNEL EQUIP

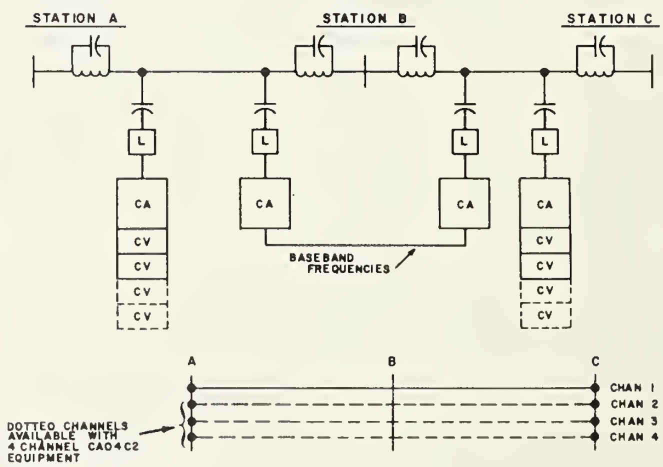


Figure II - 60 One to Four Simultaneous Voice Channels Between Two Stations With Repeater In Middle. No Provision For Telephone Drop At Station B.

H. Engineering Calculations

Two basic factors govern the channel performance. The first is the ability of the receiver to detect the transmitted signal, and the second is the magnitude of the desired signal to the magnitude of the noise signal, called signal-to-noise ratio (SNR), which results in unambigous detection.

The desired signal incurs losses in transit from transmitter to receiver. Therefore, the transmitter must have sufficient signal power to provide an acceptable signal level to the receiver after suffering the attenuation discussed in earlier sections of this bulletin.

The two basic noise types of interest are: random "white" noise, and impulse noise. Noise has been discussed in Sections II E and II F and will not be covered in this section, except for its effects. The signalling function, type of carrier transmitter/receiver, and receiver design features will determine whether impulse or random noise is most important. However, as a basis for application, random noise is more predictable and lends itself to making an analysis of carrier performance.

Random noise generally exists at a constant power level over the whole line length. However, faulty insulators, faulty hardware, or a localized storm on a long line, can cause higher noise levels at specific locations. These will incur the same attenuation as to the desired signal in reaching the receiver.

Interfering signals from other communication equipment can cause misoperation of carrier receivers. Two basic examples are: (1) beat frequencies caused by intermodulation when adjacent carrier transmitters do not have adequate isolation from each other, (2) "alien" frequencies which are in the same operating band or very near to the same operating frequency as the affected receiver.

Adjacent frequencies generated by transmitters at or near the same location must be chosen with consideration given to the "selectivity" of the receiving equipment. Proper determination of channel selectivity, frequency assignments, isolation obtainable from attenuating equipment and the required circuit configuration (including line traps), must be made for successful carrier applications.

Receiver performance capability regarding noise tolerance is given in terms of the minimum permissible SNR. This is usually expresses in dB. The SNR is determined as follows:

SNR (dB) = Signal level (dBm) - Noise level (dBm).

It should be noted that both signal and noise are attenuated by the coupling equipment and circuits at the receiving end. In a given bandwidth, thus the SNR doesn't change from the line side of the coupling capacitors to the receiver terminals.

In addition to judicious frequency selection for long lines, marginal operating conditions can be improved by using higher efficiency coupling methods, larger coupling capacitance values, higher impedance traps, and signal isolating techniques.

The carrier equipment characteristics, as well as the channel attenuation and noise, affect the overall performance of a carrier channel. The minimum SNR which will give satisfactory operation can vary widely and depends on the equipment characteristics, type of modulation, design features and signal function. The manufacturer's data and recommendations should be used in planning carrier applications.

For single function, single channel equipment, the channel performance calculation is relatively straightforward once total path attenuation and noise levels are known. The total power of the transmitter is dedicated to performing a single function and its power output directly represents the available power.

Multifunction, multichannel carrier (usually SSB equipment) requires the predefinition and calculation of a modulation assignment for each of the functions which share in common the transmitter available power output. This provides an "effective power" for each function, so that each function may then be examined to determine if its SNR criteria is acceptable. Relationships are usually recommended by the manufacturer for the relative magnitudes of the modulation voltage levels assigned to various types of input signals. A maximum permissible simultaneous modulation level of the transmitter must be observed in dividing and assigning modulating signal levels. The effective power level is then calculated in terms of dBm, for each function. For calculation of effective power, the manufacturer's recommendations should be followed.

1. Single Function, Single Channel

   A typical protective relaying channel configuration utilizing single function, single channel, type equipment for each of the relaying functions is to be used in this example. An AM (on-off) carrier would be used for line protection, and the FSK carrier for breaker failure pro-

tection and transferred trip relaying. Because impulse noise, bad weather, and line faults can be critical to high speed relaying, conservative practice usually allows greater operating margins and SNR's than for less essential functions.

PLC relaying applications are usually examined very closely. Total path attenuation is calculated from reference data, and the manufacturer's equipment performance specifications together with noise data are examined to predict overall channel performance. For this example it will be assumed that the manufacturer's performance specifications stipulated the following:

Carrier	Operating Range, dB	Min. SNR, dB
AM carrier, 10 watt	40	20
FSK carrier, 1 watt	60	10

A PLC signal attenuation calculation requires that the dB attenuation caused by each PLC equipment component (or assembly) and the attenuation caused by each power system element be determined, and that their arithmetic sum be obtained. This sample calculation will show these losses as they are encountered by a signal originating at the transmitter at Station A, and traveling to the receiver at Station B. The parameters to be used are as follows:

AM Carrier = 10 watt single frequency (on-off) carrier set
FSK Carrier = 1 watt (transmitter), frequency shift keying, 2 frequency carrier set
f_1 = 100 kHz, f_2 = 140 kHz, f_3 = 141.5 kHz
Two frequency line tuner
Coupling capacitor (.003μf)
Isolation hybrid
Z_T = Trap impedance (400 ohms in example)
Z_{TR} = 1000 ohms, shunt to ground at PLC frequency
Z_o = Characteristic impedance of 230kV transmission line, line-to-ground = 400 ohms
Z_1 = Equivalent impedance, looking into Station A
Z_2 = Equivalent impedance, looking into Station B
Z_{L1} = Equivalent load impedance seen by coupling circuit at Station A
Z_{L2} = Equivalent load impedance seen by coupling circuit at Station B

Z_A = Equivalent bus impedance, 600 ohms, shunt- to-ground, Station A

Z_B = Equivalent bus impedance, 700 ohms, shunt-to-ground, Station B

A FSK carrier transmitter/receiver isolation hybrid causes a 3.5 dB loss. Two hundred feet of coaxial cable at 140 kHz has a 0.13 dB loss. The two-frequency line tuner loss and the coupling capacitor loss are dependent on the equivalent load impedance Z_{L1} and the capacitance of the coupling capacitor. The value of Z_{L1} is calculated from the parallel combination of Z_0 and Z_1. Z_1 in turn consists of Z_T in series with the parallel combination of the five lines and equivalent (shunt-to-ground) bus impedance. Note that bus impedance-to-ground is due to capacitance-to-ground of equipment insulating bushings and bus insulators. The simplifying assumption that all impedances have the same phase angle is made; although this is not strictly correct. Thus:

$$Z_1 = Z_T + \frac{1}{\frac{5}{Z_0} + \frac{1}{Z_A}} = 400 + \frac{1}{\frac{5}{400} + \frac{1}{600}}$$

$$Z_1 = 470 \text{ ohms}$$

and:

$$Z_{L1} = \frac{Z_0 \, Z_1}{Z_0 + Z_1} = \frac{(400)\,(470)}{400 + 470}$$

$$Z_{L1} = 216 \text{ ohms}$$

At 140 kHz, the attenuation for a 216 ohm load impedance and a .003µf capacitor is 0.76 dB for single frequency resonant tuning. The attenuation for a two-frequency line tuner is approximately twice that of the single frequency tuner. Thus the coupling loss is 1.52 dB

The shunt loss incurred by the signal in the direction of Z_1 is found from:

$$10 \text{ Log}_{10} \frac{Z_0 + Z_1}{Z_1} =$$

$$10 \text{ Log}_{10} \frac{400 + 470}{470} = 2.67 \text{ dB}$$

The line attenuation is found in Section II.G.11. The total line attenuation in dB for fair weather conditions is as follows:

(dB/mi) x (miles) x (line voltage multiplier) + (coupling correction) + (transposition correction) = Line Attenuation.

The line attenuation for fair wather conditions:

$$0.125 \times 80 \times .78 + 1.0 + 0 = 8.8 \text{ dB}$$

For adverse weather conditions the total line attenuation is as follows:

$$0.125 \times 80 \times .98 + 1.0 + 0 = 10.8 \text{ dB}$$

The shunt power loss at the receiving end (direction of Z_2) is found from the equation:

$$10 \text{ Log}_{10} \frac{Z_0 + Z_2}{Z_2}$$

where:

$$Z_2 = Z_T + \frac{1}{\frac{3}{Z_0} + \frac{1}{Z_B} + \frac{1}{Z_{TR}}} = 500 \text{ ohms}$$

Thus shunt loss is:

$$10 \text{ Log}_{10} \frac{400 + 500}{500} = 2.55 \text{ dB}$$

The coupling loss is dependent on Z_{L2}.

$$Z_{L2} = \frac{Z_0 Z_2}{Z_0 + Z_2} = \frac{(400)\ (500)}{900} = 222 \text{ ohms}$$

For a 222 ohms load and a .003µf capacitor, the single frequency line tuning loss is 0.75 dB. A two-frequency tuner is twice as much, or 1.5 dB. Similar to the calculation for Station A, the loss in the coaxial cable is 0.13 dB and the loss in the hybrid unit is 3.5 dB.

The results for the FSK carrier channel losses are given below in Table II - 21. A subtotal is calculated for the attenuation from the transmitter at Station A to the 230KV lineside terminal of the coupling capacitor at Station B in the table.

Table II - 21

FSK Carrier Channel Losses

Item	Weather Conditions Fair (dB)	Weather Conditions Adverse (dB)
Hybrid	3.5	3.5
Coax	0.13	0.13
Line Tuner/Coupling	1.52	1.52
Shunt	2.67	2.67
Line Attenuation	8.8	10.8
Subtotal:	16.62	18.62
Shunt	2.55	2.55
Line Tuner/Coupling	1.5	1.5
Coax	0.13	0.13
Hybrid	3.5	3.50
Total loss:	24.3	26.3

In determining the AM carrier losses, the same procedures are followed, recognizing that 100 kHz must be used in the calculations. The results are given in Table II - 22:

Table II - 22

AM Carrier Channel Losses

Item	Weather Conditions Fair (dB)	Weather Conditions Adverse (dB)
Coax	0.11	0.11
Line Tuner/Coupling	2.2	2.2
Shunt	2.67	2.67
Line Attenuation	7.0	8.53
Subtotal	11.98	13.51
Shunt	2.55	2.55
Line Tuner Coupling	2.1	2.1
Coax	0.11	0.11
Total loss	16.74	18.27

Noise levels can be obtained from Section II.G.10. The conditions assumed are as follows:

Carrier Frequency	Weather Conditions Fair	Weather Conditions Adverse
100 kHz	- 35 dBm	- 18 dBm
140 kHz	- 36 dBm	- 19 dBm

The operating ranges and minimum SNR for the equipment given at the beginning of this section are used to calculate the predicted performance of these single function, single channel equipments.

The signal transmission requires only 18.27 dB (from Table II-22) of the AM carrier 40 dB operating range, well within its capability. The adverse weather causes a SNR of 26.5-(-18) = 44.5 dB which is well above the minimum required, 20 dB. This examination shows that satisfactory operation is to be expected.

The signal transmission requires 26.3 dB (from Table II-21) of the carrier equipment's maximum range of 60 dB, well within its capability. It must be remembered, however, that line faults can cause additional attenuation, and that tripping through a fault would leave a much smaller margin. The SNR in adverse weather is 11.4-(-19) = 30.4 dB. This is easily within the 10 dB minimum which is acceptable. Thus operating range, and SNR parameters indicate a successful application.

2. <u>Multifunction, Multichannel</u>

Two channel single sideband equipment is used to illustrate the SNR criteria which usually limit the application of multifunction, multichannel equipment. The following three values must be determined before the SNR of a carrier channel can be calculated:

Effective transmitted power
Path attenuation
Line Noise

They are discussed separately in the following paragraphs, and an example is given for calculating a typical SNR.

(a) <u>Effective Transmitted Power</u>

The following power values for the functions are typical of manufacturers' data:

Voice Effective Power	+ 26 dBm
Telemeter Tones, each	+ 20 dBm
Signaling Tone	+ 16 dBm

These values will be used to determine the SNR after the signal is reduced by the path attenuation from transmitter to the high voltage terminal of the coupling capacitor at the receiver end.

A typical value of effective transmitted power is used from manufacturers' application data. It represents the average voice signal power assigned for specific channel loading conditions, and it is simulated by a test tone.

(b) Path Attenuation

The total path attenuation is comprised of line attenuation, coupling losses and shunt losses.

The values are obtained from Sections II.F.1 and II.G.12. For illustration it is assumed that the total coupling and shunt losses at the transmitter are 6 dB.

The value for the transmitting end only is used in the SNR calculation, since receiving end losses reduce both the signal and the noise by the same amount, and, therefore, do not affect the SNR.

(c) Noise

Noise values for both fair and adverse weather conditions are required to determine if the SNR's are satisfactory. The values used in this example were obtained from Sections II.F.1 and II.G.10.

Using the same methods as the example in Section H.1, the results of the SNR calculations for the voice function are:

SNR for fair wather = 42 dB
SNR for adverse weather = 22 dB

For adverse weather conditions, this indicates a barely acceptable SNR. The means for improving this marginal SNR would be to increase transmitter power or utilize compandors. The latter is much less expensive than the former.

Compandors usually produce a 10 to 20dB improvement in voice SNR. Thus at least a 32 dB SNR could be expected and a maximum SNR of 50 dB.

SNR evaluations for the signaling tone (associated with the voice function) and the telemetering tones can be made using calculation methods similar to those used for the voice function. The following examples are based on adverse weather conditions.

For this example, the manafacturers' modulation plan allocated a 16 dBm power level to the signaling tone. The SNR for this FSK signaling function is 5 dB. Performing the same calculations with 16 dBm effective power level at transmitter, a SNR of 12 dB is obtained. Since 5 dB is acceptable, 12 dB is also.

The modulation plan allocated 20 dBm effective power level to each telemeter tone. Performing the calculations, 16 dB SNR is obtained. A 5 dB SNR for 60 baud telemetering tones is adequate, thus this application is acceptable.

III. OPERATIONS AND MAINTENANCE

A. System Structure and Operation

The unique nature of power transmission and its role in modern society introduces both problems and demands not found in other types of industrial and commercial systems. In power transmission we are responsible for moving raw power, electrical energy. When disturbances or interruptions occur in the power system almost everything around is effected to one degree or another. A breakdown in the power generation, transmission, or distribution systems can paralyze the particular area being served. Also important is the effect of a transmission breakdown on the generation and distribution network itself. Todays power transmission is a finely balanced operation in which great amounts of energy are transformed by generators into electricity and moved efficiently through the distribution networks to the users. The power generation is carefully matched to demand and network transmission capacity. Faults destroy this balance and if unchecked, could severely damage or destroy generation and transmission equipments. As a result of the importance of protecting this equipment, communications are vital. Therefore the operations and maintenance of power systems communications is paramount to the successful operation of the power system itself. The structure of communications within the REA cooperative borrower community is somewhat different than that experienced by privately owned public power utilities.

REA cooperatives and hence their communications system form a heterogeneous hierarchy of communications systems. The following cooperative facility ownership or control from a communication standpoint is possible within the REA structure:

- Generation
- Transmission
- Distribution
- Generation/ Transmission/ Distribution
- Generation/ Transmission
- Generation/ Distribution
- Transmission/ Distribution

Each combination or entity above has slightly different requirements - - some more and some less. The use of PLC and ISW may be somewhat unique depending on co-operative ownership. Any of the above may use PLC and ISW, however, when transmission facilities are not under the direct control of the cooperative coordination and agreements must be reached between and among the cooperative entities involved. Generally speaking, the responsibility for operations and maintenance of PLC and ISW will reside with the borrower effecting the loan.

In the REA structure, the operations of a PLC or ISW system must be such as to minimize costs due to traffic outages and keep the levels of cash expenditures for system upkeep to the lowest practical amounts.

B. Project Management

Dependable and reliable communications service is the goal of any cooperative-borrower communications system. The equipment that provides the communications service is an important factor related directly to the type of maintenance given such equipment.

To obtain the maximum service from a PLC or ISW system each unit should be inspected, repaired or adjusted, completely refurbished or replaced at periodic intervals during its service life. The selection of these intervals depends upon the types of equipment involved and other elements which have an effect on its operating and service life.

For these reasons the maintenance program must be developed to a point where trouble or faulty conditions are discovered and repaired before a service interruption occurs. This type of maintenance is referred to as preventive maintenance. The repairing of failed or faulty units is classified as corrective maintenance. The maintenance program should aspire to the preventive type. As such, the program should combine routine tests and inspections. A comprehensive maintenance program has the following attributes:

- A reduction in overall repair costs
- A higher quality of service to users
- The maintenance activity is carried out more efficiently and under better conditions.

The development of an effective maintenance program must be structured after the particular borrower-type system considering the following.

- If an existing system is being upgraded, a careful analysis of previous maintenance and trouble reports should be carried out.

- Field maintenance teams should be consulted as to observations and inspections.

- Review suggested vendor maintenance program for thoroughness.

Functional and performance tests carried out at the factory and during acceptance testing should be analyzed for incorporating parts or portions thereof into the maintenance testing. Usually these tests subject the equipment to critical tolerance and in this manner potential equipment failures are brought to light before a service failure.

Visual inspection plays an important role in the overall maintenance program in that a continuing effort should be carried out to observe those conditions which will eventually cause transmission impairment.

In general a maintenance program involves various routine scheduling programs. The following are typical of maintenace activities to be included in the maintenance program.

- Periodic inspections

- As required routines

- Continuous routines

- Cleaning routines

Periodic routines are those maintenance activities scheduled at regular intervals.

As required routines are those maintenance functions that are executed as a result of analyzing trouble reports indicating they are necessary.

Some transmission systems have supervisory control and alarm as part of their capability. This involves

operator interaction via observation or testing on an almost continuous basis.

Cleaning routines are one of the most effective maintenance tools - - requiring very little in the way of both skill and equipment. Dirt and dust are two of the most common sources of gradual deterioration of system performance.

To be most effective, maintenance depots or centers should be set up at those locations which result in the most rapid and cost effective response to system needs. This may, and often does, require mobile maintenance facilities and crews where the system operation is extensive. This may also require stockpiling spares at multiple locations.

Very few maintenance programs can be carried out with significant success unless the requisite planning preceeds the maintenance action.

C. Manpower Requirements

PLC and ISW maintenance and operations departments require at least one full-time senior engineer who will be completely responsible for all maintenance functions. In addition, the maintenance staff should be comprised of engineers and technicians from several specialized communications disciplines. In addition, these personnel should have a familiarity with generation, transmission, and distribution facilities and operations. For systems being either upgraded or newly acquired the maintenance and operation staff will have the responsibility for:

- Coordination of vendor testing and test programs
- Review of design and implementation of communications system
- Miscellaneous hardware manufacturers tests
- Supervise and/or install equipment
- Witness, review and approve factory, field and acceptance tests

The experience of borrowers with communications systems shows that in-house maintenance capability is superior to complete reliance on vendor field support to achieve the high degree of availability required. Utility personnel respond faster to isolate hardware problems and restore system operations when failures occur. Familiarity with the actual installation and continual performance monitoring allows maintenance personnel to detect and remedy incipient hardware problems before they result in system failures. Vendors, by contrast, normally concentrate their system maintenance engineers at headquarters. Additional time and costs are spent to effect most repairs. Constant maintenance by dedicated vendor personnel on the other hand would be far too costly. Borrowers should perform all maintenance and rely on the vendor only for extremely difficult failures and the repair of complex system problems.

The maintenance of station and line equipment should be the responsibility of highly motivated, well-trained personnel. The maintenance of communications equipment require skills beyond those of average technicians. Once trained, maintenance men are in great demand and the cooperatives must make this position an attractive one for competent individuals. Two station maintenance technicians are required to provide round-the-clock on-call support, and to assure that if one key man is not available or seeks another position the system will not be subjected to loss of all preventive and repair maintenance. Both individuals should attend all available courses covering all equipment offered by the vendors during the implementation phase of the project.

In addition, on-site installation and maintenance training should be conducted for the two maintenance engineers and a minimum of two individuals who will be used to maintain distant sites. It is recommended that a minimum of one remote maintenance site be established, to be staffed by the one maintenance technician, and that this site be equipped with test equipment and spare parts sufficient to accomplish normal repairs. Personnel for this function could be drawn from the maintenance staffs of the member co-ops during critical periods.

Valuable additional training is available during checkout of various subsystems during system integration prior to acceptance testing. Maintenance personnel are expected to play an active role in system testing at the vendor's

facility, and in installation and acceptance testing. Maintenance personnel will report to the systems engineer on the Project Manager's staff.

Acceptance of a new system implies the existence of trained personnel to operate, maintain and update it. the basic staff should consist of personnel previously assigned to the design and implementation of the project. Additional manpower may be trained subsequently and given hands-on-experience with the system.

After system acceptance, programming personnel involved in the monitoring and implementation of the new system will continue to perform daily updating and longer-range software development tests. Sufficient development work should remain to ensure the continued interest of programming personnel, and minimize diversions. These programmers will report to the digital system engineer.

D. Training

The training of maintenance personnel should be geared to achieve the following objectives: ensuring the system's availability by quickly isolating and correcting failures; ensuring that backup devices are always ready to assume on-line functions; permitting reconfiguration of hardware to match the changing electrical system; and promoting a thorough understanding of the capabilities of the communications system with its assigned staff.

Whenever possible, training courses should be conducted at convenient on-site locations. Other locations are acceptable if the technical material can best be covered there, or the number of participants is small. Training should be conducted by experienced personnel, supported by modern training aids. Individual copies of technical manuals and pertinent documentation should be given to participants at the time the course is conducted. The courses should be scheduled in a staggered manner so that one man could participate in all of them.

Training courses and most participation by borrower personnel during the system implementation will be at the vendor's facilities. Engineers and maintenance personnel must be dedicated to the project and should not be assigned to other duties until the system is successfully installed and cutover for operation.

Engineering and maintenace personnel should attend courses dealing with the hardware furnished within

three months of the integrated factory acceptance test. One course should deal with the carrier transmission equipment, its operation and capability as a diagnostic tool. The second course should cover all coupling equipments, their interface and operation. These courses should be structured to enable maintenance personnel to operate actual equipment, run diagnostics and repair failures. Additional training courses for peripheral equipment that may be provided by subcontractors should be attended if they are available. These latter courses should detail and cover all aspects of electronic and mechanical operation.

After the system has been accepted and is in operation, a continuing training program should be initiated. In this way new maintenance personnel may be afforded on-the-job maintenance training.

E. Support Requirements

A support program involves the determination of the material, manpower, tolls and methods necessary to keep the system at a level of performance commensurate with supporting the users requirements for communications. This is not always accomplished. Nevertheless, it does remain the goal of the support program.

The selection of material or spares is as much a science as the design or engineering of a communications system. In todays modular type systems, the determination of the lowest replaceable unit versus throw away spares involves intricate analysis of cost versus repairability. This is further complicated by such factors as the level of maintenance to be performed at the borrower's facility versus using the vendor's factory repair facilities. The mean time to repair and the mean time between failure criteria also bear significantly upon spare determination. These and many other considerations are involved in spares selection. It is not merely selecting some percentage of the purchase price of the system and then buying that amount of spares.

All PLC and ISW systems should have a central maintenance depot where a complete supply of spare components and plug-in assemblies are kept and where test and repair facilities are established to handle the repair of equipment used in the system. Where an extensive, wide-spread system is involved, consideration should be given to the establishment of more than one maintenance depot. The depot's function is to furnish depot overhaul, supply

support, and emergency repair services.

During the course of preventive maintenance inspections, it will be noted from time to time that the performance of some components has deteriorated. Rather than wait for the component to become weaker or to fail completely and cause system interruptions, it is considered good maintenance practice to replace such weak components during the inspection. Although components are replaced before their full service life has been realized service interruptions can be avoided in this manner. This practice will in turn increase the expected replacement parts cost for an operating system; however, the increase is justified on the basis of increased system reliability and the saving of additional manpower costs that would be incurred in making special rush trips to unattended stations to restore station operation.

In addition to adopting the proper spares philosophy, it is equally important that the proper test equipment be available for utilization by maintenance personnel. Each field maintenance man should be equipped with a complete set of portable equipment for making routine measurements. As the area of maintenance progresses from on site field maintenance to depot maintenance, the quantity and requirements of the test equipment to perform the maintenance procedures will increase. Care should be taken in the selection of the test equipment to insure that special equipment brought on site by the vendor for use in setting up and aligning the system is available as may be required for use by the borrower's engineering staff.

F. Preventive Maintenance

In order to assure continued operation of a communications system over a prolonged period with a minimum of outage time, it is essential that an adequate preventive maintenance program be established. The ultimate aim of this program should be the detection and elimination of possible fault componet failures before these conditions cause system failure. For example, routine measurements at test points and panels of the equipment should be logged so that any changes can be detected and a component or other unit which is gradually becoming defective may be replaced. Thus preventive maintenance differs from trouble-shooting and repair in that its objective is to prevent trouble from occuring rather than to correct troubles after the equipment has failed. The two main phases of preventive maintenance are:

- Mechanical and physical inspection
- Electrical measurement and testing

Mechanical and physical inspections will eliminate a large percentage of future electrical troubles. Among the items which this phase would address are:

- Impairments due to mechanical vibration
- Mechanical integrity of connectors
- Rack mounting integrity
- Dust and dirt removal from equipment
- Rust and corrosion inspection
- Peeling and chipping of painted surfaces

The above are but a few of the items involved in mechanical and physical inspections.

The second phase of preventive maintenance is the electrical measurement and testing of the system. This phase is required because a complete mechanical and physical inspection, although valuable, is not sufficient in itself for a thorough check of the system. The electrical measurement and testing phase of the electrical maintenance program should include a complete test of overall system operation. Tests should be conducted periodically. Among the elements, but not necessarily limited to, that may be tested are:

- Signal to noise ratio
- Equipment characteristic impedance
- Binary error rate as applicable
- Channel level stability
- Frequency accuracy
- Bandpass characteristics
- Line noise
- Coupling losses

- Isolation levels (where appropriate)
- Shunt losses
- Bypass losses
- VSWR
- Series losses
- Improper terminations
- Tap line effects

G. Periodic Maintenance

Preventive maintenance of PLC and ISW equipment should be performed at periodic intervals, such as weekly, monthly, quarterly, etc. The possibility of occurance of trouble in equipment can be reduced greatly by following a definitive preventive maintenance schedule. The schedule should provide for visiting each station at the designated time intervals to make routine checks and to correct any conditions which might otherwise lead to failure. The inspector should make certain that the entire station is kept clean, and that the equipment is kept free from dust, dirt and corrosion. The inspector should perform the minor duties of maintenance and refer all faults requiring specialized attention to qualified maintenance personnel.

It is essential that a complete systems check and station inspection be conducted at weekly intervals after the system is first installed. This will show the accumulation of data pertinent to the operation of the system. To accomplish the weekly maintenance procedures, it may be necessary to interrupt service for an interval of time, the length of the interval depending upon the particular equipment being checked. If service must be interrupted for this maintenance, tests should be scheduled during hours when communications traffic is normally light. It is also important that the scheduled maintenance be performed at the designated time.

In general, monthly maintenance includes all checks performed during the weekly maintenance inspection and, in addition, other pertinent measurements required to check the overall system, condition and performance.

The quarterly preventive maintenance is performed by

following the monthly maintenance procedure and, in addition, including the checks and tests necessary for the required visual and electrical inspection designated by the maintenance program.

H. Test and Evaluation

Test and evaluation is a quality assurance tool for evaluating the status, performance level, and operabilty of a communications system. The ultimate purpose of test and evaluation is to quantitatively ascertain the system's current capabilities for subsequent comparison to performance standards for a specific grade of service. Additionally, the data gathered as a result of test and evaluation may be further used to determine both the onset of potential equipment malfunction, and the system's performance during periods of gradual degradation. The parameters listed herein were derived from a set of overall performance parameters useful in determining the system's quality.

1. Significant Performance Parameters

Significant performance parameters are those electrical quantities or qualities that provide a measure or indication of the performance of an equipment unit, major portion of the system, or the system itself. The following are indicative of such parameters, but are by no means exhaustive.

- System/equipment availability
- System/equipment reliability
- System/equipment maintainability
- System/equipment operability
- Surge impedance
- Line noise (random)
- Equipment noise
- Corona noise
- Impulse noise
- Substation impedance
- Tapped line effects
- Transposition losses
- Transmit power level
- Frequency stability
- Equipment power supply and characteristics
- Equipment meter accuracy

- Audio output levels/accuracy/frequency stability
- Receiver bandwidth/selectivity/sensitivity/noise
- Received signal level
- Harmonic suppression
- Environmental-temperature/humidity
- Coupling capacitor characteristics
- Line tuner characteristics
- Line trap characteristics
- Coaxial cable losses
- Shunt losses
- Series losses
- By-pass losses
- Noise due to distortion
- Branch circuit losses
- Reflection losses
- Losses due to alternate paths at substations
- Fault attenuation
- Weather effects
- Coupling factors
- Radio interference
- Auxiliary coupling characteristics
- Isolation filter characteristics
- Surge Withstand Capability (SWC)

Again it should be noted that the above do not constitute all of the paremeters, but merely those judged to be most significant.

2. Optimum Measurable Parameters

In any given set of functions, some are more representative than others. Optimum is relative. For example, if we are speaking of testing at the factory, optimum measurable has a completely different context. If, insstead, we are concerned only with the testing possible on a system "in-place", then the number of measurable parameters is reduced drastically. Additionally, it must be born in mind that testing is a function which is done as a necessity. It should not be viewed from the standpoint as a time for experimentation--the economic factors involved dictate against such notions. The following is a group of tests which may be performed in the field. Some tests may require removing the equipment from service while others may be conducted while equipment is in operation. The testing of relay/blocking and transfer/trip equipment require great care and are beyond the scope of this section. The following parameters are

deemed to be optimum in the sense that they can be performed in the field.

- Line noise
- Intermodulation distortion noise
- Corona noise
- Impulse noise
- Transposition losses
- Transmit power level
- Surge withstand capability
- Frequency stability
- Audio output levels/impedance
- Received signal level
- Receiver noise
- Insertion losses of coupling equipment
- Coaxial cable losses
- By-pass losses
- Digital signal characteristics
- Analog signal characteristics
- Error rate
- Line attenuation
- Shunt/series losses of coupling units

3. <u>In-Service Tests</u>

The following parameters may be measured while the system is in service:

- Line noise
- Intermodulation distortion noise
- Impulse noise
- Transmit power level
- Audio output levels/impedance
- Receive signal level
- Coaxial cable losses
- Error rate
- Line attenuation
- Corona noise

4. <u>Out-of-Service Tests</u>

The following parameters are to be measured after the equipment or major units are removed from service:

- Transposition losses
- Surge withstand capability
- Frequency Stability
- Receiver noise
- Insertion losses of coupling equipment
- By-pass losses
- Digital/Analog signal characteristics

5. Acceptance Tests

This section deals with those tests and evaluations which are to be conducted prior to system cutover which provide verification of equipment design and system performance.

a. Reliability

Reliability is defined herein as a measure of this equipment's or system's ability to perform its intended function under specified conditions for a specified period of time. It is a probability figure, based on failure data and length of operating time. The reliability of system components is reflected in their respective Mean-Time-Between-Failures (MTBF) number. This "figure of merit" is used in the calculation of the system availability as defined in paragraph (c) that follows. The design goal for equipment should be:

- No single component failure anywhere in the system shall result in a critical failure (e.g., false operation of external device)

- Where feasible, multiple component failures shall be protected against; particularly, where devices have high failure rates and/or potentially long repair times.

Reliability models and predictions made by the supplier should be in accordance with the guidance contained in MIL-HDBK-217.

Failure distributions show the manner in which failures occur -- i.e., the way in which failures are distributed as a function of time. The supplier of equipment covered by this standard should maintain failure distribution data for all components, assemblies and units that by their failures can cause a critical and/or major failure of the total system. Failure distribution data should be documented as shown on MIL-HANDBOOK-217A and be made available for review upon request. This responsibility is for equipment in the possession of the supplier and for those user owned field units for which data is available.

Manufactured and/or vendor procured parts and components that can cause a critical or major system failure are subject to the requirements of this paragraph.

b. Maintainability

Equipment covered by this standard shall be maintainable by skilled, trained personnel at a service facility and in the field. For this purpose, the operating parts shall be field removable from their enclosure as a single, compact assembly. Suitable grips or handles shall be provided to facilitate safe removal and installation of heavy or bulky assemblies.

Efforts to attain standardization of units, subassemblies, connectors, etc. shall be accompanied by provisions to facilitate indentification and preclude improper mounting and installation. These provisions shall include, but not be limited to

- Physical provisions to preclude interchange of units or components of a same or similar form that are not in fact functionally interchangeable.

- Physical provisions to preclude improper mounting of units or components

- Provisions (e.g., labels) to facilitate identification and interchange of interchangeable units or components

- Provisions (e.g., alignment pins) to facilitate proper mounting of units and components

- Measures to insure that identification, orientation, and alignment provisions include cables and connectors.

- Positive identification of groundable parts

The maintainability of system components is reflected in their respective Mean-Time-To-Repair (MTTR) number.

The supplier shall be responsible for providing upon request a quantitative list of replacement

parts deemed necessary to meet the availability and MTTR requirements as discussed below. In establishing the number of parts on hand, the supplier shall take into consideration the time required to return a failed component (field or factory maintenance) to a serviceable condition.

The MTTR values used by the supplier in his availability computations should be based to the maximum extent possible upon maintenance experience. MTTR values normally include

- Administrative time -- the time interval between the failure of a component and a call for maintenance service

- Transport time -- the time interval between the call for maintenance service and the arrival at the station of a maintenance technician and the necessary replacements parts

- Repair time -- the time required by a trained maintenance technician with replacement parts and recommended test equipment at the station to restore normal operation at the failed system.

When insufficient maintenance experience has been accumulated to provide MTTR values, Test Method 1 of Appendix B, "Test Methods and Data Analysis", from MIL-STD-471A should be used. The supplier shall document in the appropriate maintenance publications (see paragraph 10.5) the preventative maintenance requirements for all mechanical units (disk drive motors, printers, keyboards, etc.). The preventative maintenance program should be designed to prevent component "wear-out" failures.

System self-tests (or diagnostic) functions should be designed to localize any malfunction to the lowest replaceable unit level.

Test points and break points shall be readily accessible for fault isolation.

The provision of a simulator within the immediate area for the remote equipment connected to the unit under test is encouraged. The provision for storage within the equipment's cabinet of

selected spare components is encouraged.

The placement of components on cards shall be such that access is provided for test probes and connectors.

The equipment shall exhibit no malfunction or degradation of performance due to shocks from normal test bench handling. Shocks occurring during servicing may be simulated on a solid horizontal wooden bench top (at least 1-5/8 inches thick) by dropping a unit or assembly as follows:

Step 1 -- Pivoting the unit on one edge, lift the opposite edge until any one of the following alternate conditions occurs:

- The bottom of the housing forms an angle of 45° with the bench top.

- The lifted edge of the housing has been raised 4 inches above the bench top.

- The lifted edge is just below the point where the unit is balanced on its pivoting edge. Let the unit drop to the bench top. Repeat, using other practical edges of the bottom of the housing as pivot points.

Step 2 -- Repeat Step 1 with the housing resting on other faces.

Knobs should be provided in preference to screwdriver adjustments whenever frequent adjustment must be performed. If screwdriver adjustments must be made without the aid of vision, mechanical guides for the screwdriver shall be provided or the screw shall be mounted so that the screwdriver will not move out of position.

Sensitive adjustment points shall be located or guarded so that adjustments will not be disturbed inadvertently.

Internal controls should not be located close to dangerous voltages, or any other hazards. If such location cannot be avoided, the controls shall be appropriately shielded and labeled.

c. Availability

Equipment should be designed for useful life of ten years or more with a 1 year guaranteed system hardware availability measured relative to major failures.

Note: Availability in excess of 95% usually requires the inclusion of redundant elements.

Availability is defined as:

$$A = \underline{\text{uptime}} / (\text{uptime} + \text{downtime})$$

Downtime in the above equation normally includes corrective maintenance, preventive maintenance and system expansion downtimes if such times compromise the user's ability to operate apparatus normally controlled by the equipment being expanded.

The above equation for availability shall be used to compute the availability of installed equipment during the demonstration period. The equipment's operating and maintenance records shall be used to support the computations.

For design analysis and to determine an a priori prediction of availability, the following equation utilizing MTBF and MTTR shall be used.

$$A_p = \text{MTBF} / (\text{MTBF} + \text{MTTR})$$

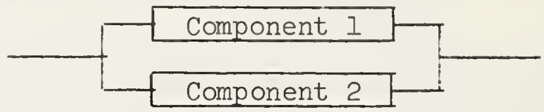
where

A_p = Predicted Availability of a component.

The equation for A_p and the combinatorial equation expressed below for parallel redundant components (or subsystems) is valid under the following conditions:

- The failure of any component within a string or parallel set is independent of the failure of any other component. In other words, component failures do not propagate failures of other components.
- Sufficient repair facilities and standby replacement parts are available in order to handle multiple simultaneous failures.

When active redundant components are used in the construction of equipment governed by this standard



The combinatorial equation* for their combined availability is as follows:

$$A_c = A_1 \times A_2 + A_1(1-A_2) + A_2(1-A_1)$$

where

A_c = availability of the combined units

A_1 = availability of component number 1

A_2 = availability of component number 2

The three terms that are added in the equation are the availabilities for each of the states that the combined units can successfully operate, namely:

$A_1 \times A_2$ = both components available

$A_1(1-A_2)$ = component no. 1 available and component no. 2 unavailable

$A_2(1-A_1)$ = component no. 2 available and component no. 1 unavailable

If the active redundant components have identically the same availabilities (e.g., $A_1 = A_2$) then

$$A_c = 2A-A^2$$

Availability block diagrams used and accompanying the availability computations shall be documented in accordance with the requirements of paragraph 10.1

* Combinatorial equations for more complex designs shall be formulated by the supplier using Section 3.0 of MIL-HDBK-217 for guidance.

Since a priori calculations for availability are made with mean values, the sensitivity of the equipment design to variations to MTBF and MTTR should be ascertained. It is recommended that equipment availabilities be computed for 10 and $\pm$ 20 percent variations in both MTBF and MTTR.

The impact of an outage of a single remote station on the availability of the total supervisory system should be defined by the user.

d. Acoustic Interference Limitations

The equipment to be installed in the same vicinity as operating personnel or in an environment where maintenance personnel will be required to perform their duties shall not produce via any means acoustic levels in excess of those specified in this subsection. The acoustic energy shall be controlled to the extent that it does not cause personnel injury, interfere with voice or any other communications, cause fatigue or in any other way degrade the environment in which it is installed. Noise generated by equipment shall not exceed NC-30 for control room installations and NC-45 for maintenance area installations as in MIL-STD-1472A.

e. Certified Design Tests

These are the tests performed by the vendor on specimens of a generic type of production model equipment to establish various operating parameters of that genre of equipment. Such parameters might include temperature range, Surge Withstand Capability (SWC), systems accuracy, etc. The conditions and results of these tests should be fully documented and certified so that they can be accepted, at the user's discretion, in lieu of factory or field test for conformance to these parameters.

f. Factory Tests and Inspections

Factory tests are performed on the actual equipment to be supplied to the user, and include all functtional tests and inspections that are performed prior to shipping the equipment from the vendor's facility. This stage also includes the inspection and approval of drawings prior to fabrication of the equipment.

The factory tests should be designed to demonstrate as completely as possible, that the equipment will perform correctly and reliably in it's ultimate installation. At the user's discretion, factory tests may also include general parameter tests to verify some or all of the results of the certified design test.

g. Field Tests

Field tests and inspections include all those performed on the equipment after it has been shipped from the vendor's plant. These may include pre-installation tests and inspections and tests to insure that it has not been damaged during shipment, and post-installation tests to verify that it performs it's functions reliably and correctly. It may be appropriate that some on the field tests be performed by the user's personnel under the supervision of the vendor's representatives.

h. Interface Tests & Inspections

These tests are designed to demonstrate that the various mechanical and electrical interfaces to the equipment are in accordance with applicable specifications, together with other applicable paramaters called out in the user's specifications, and will result in safe, correct and reliable installation and operation of the equipment. For the most part, these interface parameters can either be demonstrated during factory tests, or accepted on the basis of certified design tests.

i. Mechanical

The purchaser should verify through drawing approval and MIL-TFD.41, or factory inspection that tht mechanical characteristics of the equipment conform to the requirements of his specifications. These characteristics would include such items as materials, workmanship, dimensions, fabrication techniques, finishes, etc.

j. Electrical

These tests should include all those to be performed on electrical interfaces to the equipment, with the exception of those related to the functional performance of the equipment.

(1) Power Supply

Power inputs to the equipment should be tested to demonstrate that the equipment can operate thoughout the range of the specified power source.

(2) Surge Withstand Capability (SWC)

All inputs and outputs to the equipment exposed to a substation electrical environment, unless otherwise specified, should conform to the ANSI Standard Code C37.90A. Surge withstand capability is normally verified during the certified design test stage, during factory tests.

(3) Dielectric Tests

The dielectric test voltages for devices and apparatus other than those covered below will be found in the standards that apply to them.

Supervisory and data acquisition equipment connected to control sources rated 60 volts or less shall be capable of withstanding a 60Hz high potential test for 1 minute of 500 volts rms between outgoing terminals and ground.

k. Environmental Tests

These tests are designed to demonstrate that the equipment will perform correctly and reliably while exposed to the applicable environmental parameters together with other applicable parameters called out in the user's specifications. The results of certified design tests are usually sufficient to demonstrate that the equipment will operate reliably and correctly within a specified environment. The user, at his discretion may require the vendor to perform factory tests on the purchased equipment to demonstrate that it will indeed perform correctly under the specified entironmental conditions. Equipment in environmental test should be operating with realistic input and outputs.

The environmental parameters and testing requirements specified by the user should be limited to the worst case conditions that can be realistically anticipated in the location where the equipment will ultimately be installed.

l. Physical

The equipment should be tested to verify that it operates correctly in the following physical environmental characteristics

(1) Temperature

To test the equipment within the specified tempertature range, it must be placed in an environmental test chamber where it can be operated for a specified period at both the low and high ends of the range, as well as cycled rapidly bewteen them. Where appropriate, calibration and accuracy checks should be made at both ends of the range, so to verify performance throughout the the temperature spectrum. Testing of the temperature range is most appropriately done during the certified design test stage.

(2) Humidity

Humidity tests should be performed in conjunction with the temperature test above. For a complete test, the equipment should be exercised at both ends of the humidity range while at each end of the temperature range. Such tests should be conducted during the certified design test stage.

(3) Altitude/Pressure

Altitude and pressure tests can be performed by placing the equipment in a pressure chamber and adjusting the air pressure to the equivalent of the specified altitude or pressure.

(4) Dust

Where required, equipment should be tested to demonstrate that it will perform properly in a dusty environment. Testing may consist of inspection to determine whether or not the equipment is properly sealed to prevent intrusion of dust.

m. Burn-In Tests

The user, at his discretion, may call for a burn-in test during which the equipment is powered up for

a specified length of time. The purpose of a burn-in test is to expose those components that are prone to infant-mortality failures. Three levels of burn-in tests can be conducted; No functional exercise of the equipment, periodic functional of the equipment, and continuous functional exercise of the equipment. Time accumulated in the performance of other factory tests usually is applicable toward the burn-in period. Typical time for such a test ranges from 10 to 100 hours. Burn-in tests are usually limited to equipment for which field repair is unusually difficult.

n. Documentation Validation

The final phase of the factory tests is to verify that the documentation being supplied is an accurate and useful description of the equipment, including all corrections resulting from the performance tests. The equipment should not be shipped without marked up or corrected copies validated by the vendor. Final issue of completed documentation should be provided as soon as practical after shipment of the equipment. The vendor should also be responsible for making any changes for which the need arises during field tests.

o. Performance Tests

Performance tests shall be designed to assure that the equipment performs its functions reliably and correctly. They are performed during the factory or field test stages. For many applications and types of equipment, successful factory tests will be a sufficient basis for acceptance of the system by the user. For more complex applications or systems, however, additional tests in the field may be required to fully verify correct and reliable performance. The performance paramaters to be tested will be selected from among those given in sections III. I. 2 through III. I. 3, above.

6. Final Inspection

Final inspection is essentailly a visual mechanical inspection of the delivered end product subsequent to acceptance testing and cutover, but prior to accepting for transfer of title.

The equipments governed in this standard, as well as major sub-assemblies hereof, should be identified so that each equipment can be easily correlated with the documentation. The means of identification should be uniform throughout the system and it might include color coding, labling, part number, etc. The identification mark should be permanently affixed to the part that identifies, and it also includes functional requirements for testing and maintenance.

The system should be furnished with nameplates bearing the following information: manufacturer's name, address, identification reference, rated voltage (AC or DC or both), rated continuous current, and rated frequency (if necessary). Nameplates should be legible at a distance of 1 meter.

The system should be furnished with warning sign of safety instructions where there is a need for general instructions relative to safety measures (e.g., supply circuit).

The system should be furnished with warning signs or safety instructions where there is a need for general instructions relative to safety measures (e.g., supply circuit).

The following are some of the visual mechanical inspections to be performed:

- Inspect cable and cable connectors for mechanical integrity
- Inspect components for cracks, chips, discolorations and blistering
- Inspect meter casings for cracks and dirt
- Check indication lamps for loose bases, dirty and loose or corroded connections
- Inspect inside and outside of equipment racks and cabinets for dust, rust, and corrosion

- Check mechanical integrity for all equipment connections

- Verify rigidity and mounting of all units and cabinets

- Check mechanical grounding connections

- Insure that all required connecting cables, jumpers and test equipment have been delivered and inventoried

7. <u>Test Schedule</u>

The following parameters are to be measured at the intervals suggested:

<u>Weekly</u>

Transmit power level
Audio levels and impedances
Receive signal level
Line noise

<u>Quarterly</u>

Intermodulation distortion noise
Impulse noise
Coaxial cable losses
Error rate
Line attenuation
Corona noise
Frequency stability
Reciver noise

<u>Yearly</u>

Transposition losses
Surge Withstand Capability (SWC)
Insertion losses of coupling equipments
By-pass losses
Digital analog signal characteristics
Shunt series losses of coupling units

IV. GLOSSARY OF TERMS

Amplitude Modulation - The process of varying the amplitude of a continuous high-frequency wave (known as the carrier) in direct relation to the amplitude variations of the signal to be transmitted.

Amplitude Modulated Wave - One whose envelope contains components similar to the form of the signal to be transmitted.

Attenuation - A general term used to denote a decrease in magnitude of a transmitted signal from one point to another. It may be expressed as a ratio or, by extension of the term in decibels (dB).

Audio Frequency or Audio Tone Frequency - A frequency between 20 and 15,000 Hz.

Automatic Frequency Control (AFC) - A self-acting compensating circuit that maintains the carrier oscillator output within narrow limits of an assigned frequency.

Automatic Load Control - A control system in which raise and lower impulses from a suitable controller are transmitted by carrier to influence the governor adjustment of one or more generators.

Auxiliary Unit - The chassis unit used with a carrier transmitter to adapt the carrier channel to a specific purpose.

Back-to-Back Repeater - The process of repeating a signal at line frequencies with no local drop. The receiver output is connected to the transmitter input; the transmitter being at a frequency different from that of the receiver

Baseband Repeater - The process of repeating a signal at the baseband level (one stage of demodulation). The signal is remodulated and transmitted at a different frequency.

Balancing Network - An arrangement of impedances connected to one branch of a hybrid to match the impedance of the line connected to the opposite branch.

Beating - The linear addition or subtraction of two frequencies, which produce a third frequency pulsating in amplitude.

Beat Note - The third frequency produced by beating.

By-Pass - The act of removing the carrier signal from one line and reinserting the same signal onto a second line. By-pass is

necessary to get around a power bus, open disconnect, or other discontinuity

Carrier Channel - All elements that make up a complete carrier-current circuit between two or more points, including both the carrier apparatus and the power lines.

Carrier-Current - The art of applying low voltage, high-frequency energy directly to high voltage power lines, wire lines, or static wires for the purpose of providing various forms of communications. Carrier-current frequencies generally used are in the range of 8 to 300 kHz.

Carrier-Current Choke Coil - A reactor frequently connected in series between the potential tap of the coupling capacitor and potential device transformer unit, to present a low impedance to 60 Hz power current and a high impedance to carrier frequency current. Its purpose is to limit the loss of carrier-frequency energy through the potential device circuit.

Carrier-Current Drain Coil - A reactor connected between the carrier-current lead and ground, to present a low impedance to the flow of power current and a high impedance to carrier-frequency current. Its purpose is to prevent high voltage at power frequency from being impressed on the carrier-current lead, and to limit the loss of carrier-frequency energy to ground.

Carrier-Current Lead - The connection from the coupling capacitor to the carrier-current assembly or line tuner.

Carrier-Current Grounding Switch and Gap - A protective gap for limiting the voltage impressed on the carrier-current lead-in and the line tuner (if used); and a switch which, when closed, solidly grounds the carrier equipment for maintenance or adjustment without interrupting either high-voltage line or potential-device operation.

Carrier Frequency - The frequency generated by the carrier transmitter and impressed, with or without modulation, onto the power line.

Carrier Signaling - A carrier-frequency tone transmitted on each voice channel for control functions and dial signaling.

Carrier System - Usually refers to all the interconnected carrier terminals using the same carrier frequency.

Carrier Terminal - All of the carrier-current apparatus of one channel located at one station or location.

Channel Modem - That part of the SSB multiplex equipment which provides the first stage of modulation (channel carrier modulated by external signal, voice, tone, etc.), for transmission, and the final stage of demodulation for reception.

Characteristic Impedance - The ratio of an applied potential difference to the resultant current at the point where the potential difference is applied, when the transmission line is of infinite length.

Common Equipment - Carrier equipment that is common to two or more channels (carrier generation, group, etc.).

Compandor - A pre-emphasis device which compresses the audio signal level at the transmitter into a narrower range nearer the maximum level. At the receiver, an expandor reverses this process. This allows the signal to be transmitted at nearer maximum level and provides a significant signal-to-noise improvement in the speech signal.

Coupling Capacitor - The assembly used to isolate the carrier-current equipment from the high-voltage line, and also to couple the carrier signal to and from the power line.

Crosstalk - The energy transferred to an adjacent channel when a test tone is inserted in a channel at normal signal level.

Cutoff Frequency - That frequency at which the signal is attenuated 3.0 dB below the average level of the band.

Decibel (dB) - Commonly used for expressing transmission gains, losses, levels and similar quantities. It is a division of the logarithmic scale such that the number of decibels is equal to ten times the logarithm to the base of ten (10) of the power ratio.

dBA - Weighted noise power in dB referred to 3.16 picowatts (-85 dBm) which is 0 dBA.

dBm - Ratio expressed in decibels referred to one milliwatt.

dBm0 - Expresses a level referenced to a system test tone level. - 10 dBm0 expresses a level of 10dB below the system test tone.

dBrn - Decibels above referenced noise. - 90dBm corresponds to 0 dBrn.

Dial Signalling - Denotes a type of telephone signaling in which pulse trains are transmitted to a receiving terminal to operate automatic line-selection equipment.

Duplex - As applied to power line carrier, a system of communication in which transmission and reception are carried on without manual switching between the talking and listening periods, similar to the operation of public-telephone systems.

Echo - A signal that is reflected from some point, or points, in a circuit because of impedance mismatch, and returns to its originating point with sufficient magnitude and delay to be distinctly recognized.

"E" Lead - The incoming control lead on a carrier channel, which is controlled by the "M" lead on the opposite end.

Four-Wire Circuit - A two-way circuit using two paths so arranged that the electric waves are transmitted in one direction by one path and in the other direction by the other path.

Four-Wire Terminating Set - A hybrid arrangement by which four-wire circuits are converted to a two-wire basis for interconnection with other two-wire circuits.

Frequency Shift - A method of transmitting different control or indicating impulses by shifting the transmitted carrier frequency upward or downward. Corresponding relay (or solid-state switching) circuits in the receiver operate when they distinguish a frequency shift.

Frequency Modulation - The process by which the frequency of a continous high-frequency wave (carrier) is varied in direct relation to the amplitude of the signal transmitted.

Frequency-Modulated Wave - A wave whose frequency has been varied in direct relation with the amplitude of the signal transmitted.

Harmonic - A sinosoidal wave whose frequency is an integral multiple of a fundamental frequency.

High-Pass Filter - A filter designed to pass all frequencies above a certain predetermined cutoff frequency, and attenuate all frequencies below.

Hybrid - A bridge type circuit, or connecting device, that provides impedance matching between certain circuits, and isolation between others.

Hybrid Balance - A simple hybrid has four sets of terminals, one connected to a two-wire line, two connected to the send and receive of the four-wire line, and one connected to a network designed to simulate the impedance of the two-wire line. The degree to which the two-wire line impedance is simulated is known as hybrid balance.

Impedance Matching Transformers - A device for tying together lead-in circuits of different impedances or lengths.

In-Band Signaling - Signaling which utilizes frequencies within the voice, or intelligence, band of a channel.

Interface - The physical and electrical requirements for interconnecting two equipments or systems.

Interference - Any unwanted frequency or surge, regardless of duration, which causes a noticeable effect in the output circuit of a receiver.

Leakage - Loss of carrier energy due to an excessive number of insulators, high-shunt capacitance, inadequate or dirty insulators, or poor dielectric properties of the insulation.

Leased Facilities - Services leased from a public telephone company for the exclusive use of the power company for communication, pilot relaying, control, telemetering or indication.

Line Coupling - The Coupling capacitors, line tuning, line traps, and lead-in circuits which together provide a suitable connection between the power or telephone line and the carrier transmitter-receiver assembly.

Line Differential Relaying (same as Pilot Relaying) - A form of protective relaying whereby conditions at the end terminals of a line section are compared through high-speed communications to locate a fault on the power system and clear it with minimum disturbance.

Line Trap - A series inductance shunted by a tuning capacitor, inserted in series with the power, or telephone, line to reduce the loss of carrier energy and variations in line attenuation caused by switching or faults in the line beyond.

Line Tuning Unit - A chassis unit or module containing adjustable tuning inductances, and sometimes also drainage and surge-protective devices and impedance-matching transformers, for matching the impedance of the carrier equipment to that of the transmission line.

Line Tuner - An assembly, usually in an outdoor cabinet, containing one or more line-tuning units.

Local Drop - A point where one or more channels of a multichannel system terminates (drops) between the end terminals of the system.

Local Traffic - Any and all communications which originate at any one station.

Lower Sideband - The frequency, or group of frequencies, located below the carrier, produced by a modulation process.

Low-Pass Filter - A filter designed to pass all frequencies below a certain predetermined cutoff frequency, and attenuate all frequencies above.

"M" Lead - The control lead extending from the carrier channel to the telephone exchange or applicable control device. It is to control the outgoing signaling, which in turn controls the remote "E" lead.

Modulation - The combining of some lower frequency, usually speech or audio tones, with the fundamental carrier frequency.

Multiplex - A means of transmitting two or more signals over the same medium simultaneously.

Multiplex Channel - A carrier channel which provides two or more services.

Noise - Any extraneous sound or interference signal which interferes with a desired signal.

Noise Level - The strength of the extraneous noise; usually measured in decibels.

Off Hook _ The condition existing in a telephone circuit when the receiver, or handset, is removed from its cradle.

On Hook - The condition existing in a telephone circuit when the receiver, or handset, is resting in its cradle.

Operating Range - The operating range of a specific transmitter and receiver equipment is the attenuation expressed in decibels through which satisfactory operation is possible when no interference exists.

Out-of-Band Signaling - Signaling which utilizes frequencies within the bandwidth of the channel modem, but outside the voice frequency band.

Party Line - A subscriber line serving two or more subscribers.

Phase-to-Ground Coupling - When coupling is made to only one conductor of the power line, utilizing ground return.

Phase-to-Phase Coupling - When connection is made between two different conductors of the same power line.

Pilot - A carrier frequency transmitted for the purpose of frequency lock and automatic gain control regulation.

Pilot Signal - A signal used in conjunction with protective relaying, either on wire line, carrier, or microwave.

Potential Device - A transformer network assembly suitable for use with a carrier coupling capacitor to obtain potential indication for synchronizing, relaying, etc. This device is usually mounted in the base of the coupling capacitor and it may be arranged for carrier coupling also.

Power Output - Usually refers to the unmodulated carrier output in watts at the transmitter output terminals.

Preferential Service - A feature of some dial-telephone carrier assemblies which permit designated extension lines to break into a conversation while another extension of the same terminal is in use.

Private Automatic Branch Exchange (PABX) - A fully automatic dial telephone exchange.

Private Branch Exchange (PBX) - A telephone switchboard having provision for manual interconnection of telephone lines and carrier channels.

Rack Unit - The term used with rack-and-panel assemblies to indicate the usable height provided by a standardized supporting rack. One rack is equal to 1 3/4 inches.

Receiver Assembly - A complete assembly, usually in an enclosing cabinet, containing a carrier-receiver unit, auxiliary circuits, protective units, etc.

Receiver Unit - A standard chassis unit containing only a basic carrier-current receiver.

Reflection - A phenomenon resulting from impedance mismatch, and in carrier applications sometimes caused by tapped or dead-ended lines that are not equipped with line traps at their junction with the main circuit.

Selectivity - The performance of an apparatus (such as a carrier receiver) with respect to the acceptance of a desired frequency, or band of frequencies, to the exclusion of undesired frequencies.

Sensitivity - The minimum input required by a device to enable it to perform its function properly.

Signal-to Noise Ratio - The ratio, at any point in a circuit, of signal power to total circuit noise power.

Simplex - A system of carrier communication in which a manual switch usually a button switch on the handset, is pressed during transmission to cut out the receiver and turn on the transmitter.

Single-Sideband Suppressed Carrier - The modulation process which results in the partial, or complete, elimination of the carrier and all components of one sideband.

Sub-Multiplexing - The practice of putting more than one signal in one channel.

Supervisory Control - A system of control which provides both selective control and automatic indication of the condition of position of a number of devices located at a distant point.

Telemetering - A system of measuring at a distant point the varying changes which take place in a locally measured quantity such as voltage, current, etc.

Test Tone - A tone used for making measurements and adjustments in the 600ohm audio portion of a circuit. Its level is one milliwatt (0dBm) with a frequency of 1,000 Hz, and is applied at the zero-transmission level reference point.

Transmitter Assembly - A complete assembly, usually in an enclosing cabinet, containing a carrier transmitter unit, auxiliary and protective circuits, etc.

Transmitter Unit - A standard chassis unit containing only a basic carrier current transmitter.

Transmitter-Receiver Assembly - A complete assembly, usually in an enclosing cabinet, containing both a transmitter and a receiver unit, plus all necessary auxiliary circuits.

Trunk - A telephone circuit connecting two telephone exchanges not at the same location.

Trunk-Line Carrier Channel - A specific type of carrier telephone employing two frequency carrier equipment designed to provide services equivalent to a trunk.

Two-Wire Circuit - A two-way circuit in which the send and receive audio signals travel along the same electrical circuit.

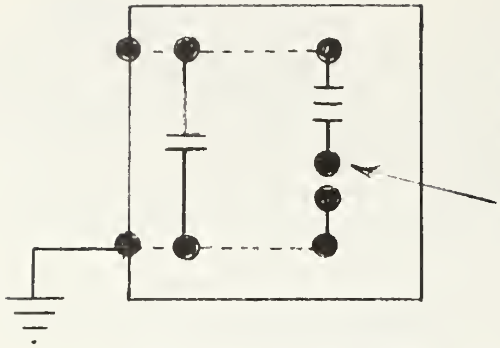
Upper-Sideband - The frequency, or group of frequencies, located above the carrier, produced by a modulation process.

<u>Wavelength</u> - The distance between successive peaks of the same polarity in a wave.

V. STANDARD SYMBOLS

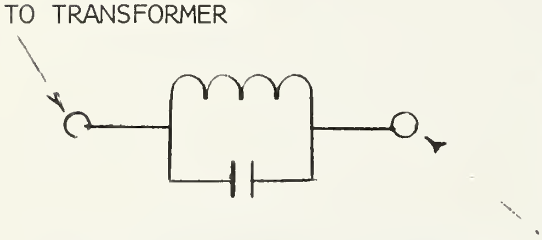
This section presents some of the basic symbols found in power line carrier schematics. While they may seem few in number, they actually represent most of the common elements used. It should be recognized that while the symbols shown are basic representations, most of the symbols represent those one will come across in PLC work, either as they are shown, or with slight variations.

The symbols shown here may not represent all of those which may constitute a particular system, but are included here as those typical in most cases.



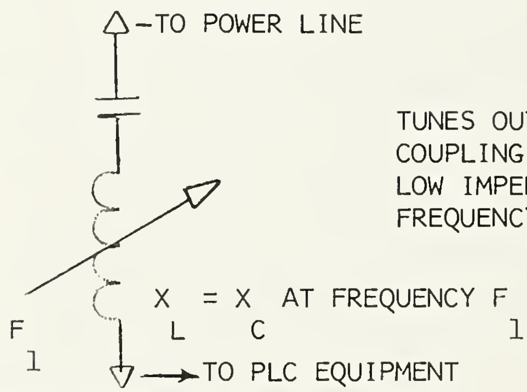
PROVIDES A LOW IMPEDANCE PATH TO GROUND AT THE POWER FREQUENCY

DRAIN COIL ASSEMBLY



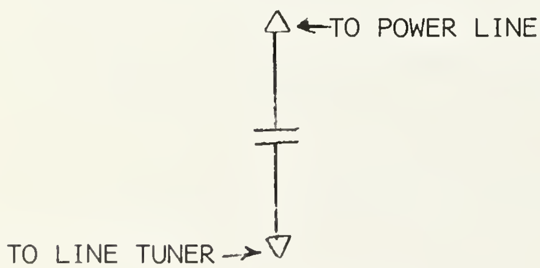
PRESENTS A HIGH IMPEDANCE TO CARRIER FREQUENCIES AND ISOLATES CARRIER CHANNELS FROM ONE ANOTHER TO PREVENT INTERFEREMCES

LINE TRAP (SINGLE FREQUENCY)



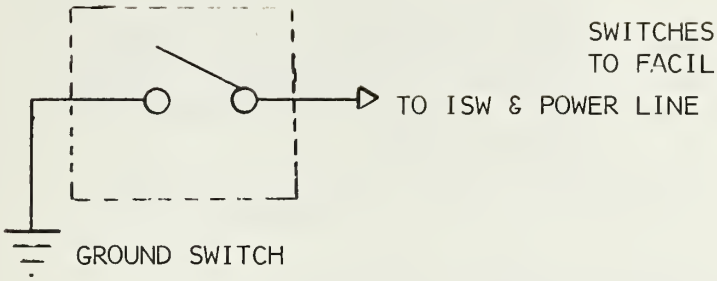
TUNES OUT CAPACITIVE REACTANCE OF COUPLING CAPACITOR AND PRESENTS LOW IMPEDANCE PATH TO COUPLE CARRIER FREQUENCY ONTO POWER LINE

BASIC SINGLE FREQUENCY LINE TUNER



COUPLES THE CARRIER SIGNAL TO THE POWER LINE

COUPLING CAPACITOR

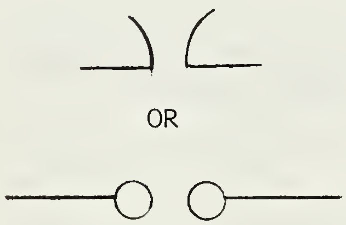


GROUND SWITCH

SWITCHES POWER LINE TO GROUND TO FACILITATE SAFE TESTING AND MAINTAINANCE

LIGHTNING ARRESTER

ARRESTS LIGHTNING AND OTHER SURGE VOLTAGE PEAKS

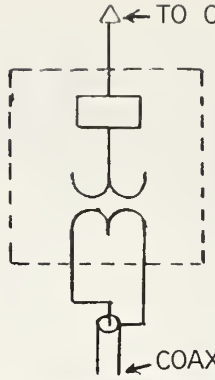


ARC GAP

USED TO BYPASS THE COUPLING UNIT DURING FAULT CONDITIONS

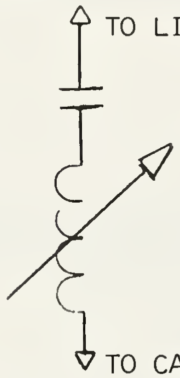
GROUND

A GROUND RETURN ASSURES THAT A VOLTAGE PORTENTIAL DOES NOT EXIST BETWEEN THE VOLTAGE POINT AND GROUND



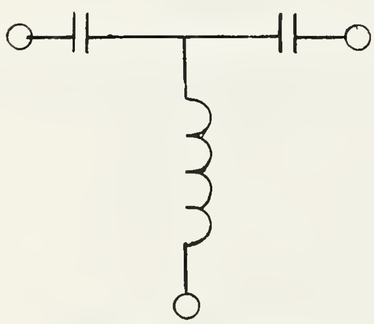
REDUCES THE EFFECTS OF COUPLING-CAPACITOR REACTANCE AND "MATCHES" THE OUTPUT IMPEDANCE OF THE CARRIER EQUIPMENT TO THE IMPEDANCE OF THE POWER LINE FOR MAXIMUM TRANSFER OF CARRIER ENERGY

LINE TUNER & IMPEDANCE MATCHING TRANSFORMER



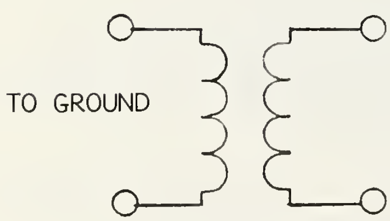
SIMPLE FORM OF BANDPASS FILTER PROVIDING LOW-LOSS PATH FOR THE CARRIER FREQUENCY BAND TO WHICH IT IS TUNED WHILE PROVIDING HIGH ATTENUATION TO OUT-OF-BAND FREQUENCIES

SERIES L/C UNIT



USED TO BLOCK THE POWER FREQUENCY AND LOWER ORDER HARMONICS

HIGH PASS FILTER



TRANSFORMS A LOW VOLTAGE TO A HIGHER VOLTAGE, OR VICE VERSA

TRANSFORMER

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International System of Units

In December 1975, Congress passed the "Metric Conversion Act of 1975." This Act declares it to be the policy of the United States to plan and coordinate the use of the metric system.

The metric system, designated as the International System of Units (SI), is presently used by most countries of the world. The system is a modern version of the meter, kilogram, second, ampere (MKSA) system which has been in use for years in various parts of the world.

To promote greater familiarization of the metric system in anticipation of the U.S. converting to the system, REA is including metric units in its publications. This bulletin has, therefore, been prepared with the International System of Units (SI) obtained from ANSI Z 210-1976 - Metric Practice. Approximately equivalent Customary Units are also included to permit ease in reading and usage, and to provide a comparison between the two systems.